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BEARING AND SEAL TECHNOLOGY REVIEW

By

A. F. Hiegel

June 1971

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U. S. ARMY AIR MOBILITY RESEARCH AND DEVELOPMENT LABORATORY
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13 ABSTRACT

Pratt & Whitney Aircraft large and small engine main shaft bearings and seals were reviewed (1) to identify large gas turbine engine bearing and seal concepts or characteristics which are applicable to small gas turbine engines of the 2-10 lb/sec airflow size, (2) to define large engine bearing and seal design standards for applicability to small gas turbine engines, (3) to determine suitable factors for scaling bearing and seal technology concepts from large gas turbine engines to small, 2-10 lb/sec airflow size turbine engines, (4) to recommend test programs to provide scaling data where scale factors are questionable, and (5) to determine what bearing and seal technology is lacking for advanced small engines.

To accomplish this task, bearing and seal characteristics that might define standard design practices or scale factors were selected. After collection and compilation of pertinent data, comparisons were made to establish relationships between engine size and selected bearing and seal characteristics. In addition, comparisons of selected characteristics of large, mostly twin-spool engines versus small engine bearing, seal, and rotor dynamic characteristics were made.

As a result, scale factors were obtained between total corrected airflow into the engine and several low rotor ball bearing characteristics. Similarly, high rotor roller bearings were found to scale with corrected airflow into the high compressor. In general, bearing and seal size was found to increase with engine size.

Although scale factors were obtained, their utilization should be confined to preliminary design only. This recommendation is made because of the many areas which can affect bearing design.

Several research programs are recommended to provide bearing and seal technology which is lacking for advanced engines. These programs include areas such as advanced bearing and seal analysis programs as well as seal wear and roller dynamics studies.

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This report was prepared by Pratt and Whitney Aircraft, Florida Research and Development Center, a Division of United Aircraft Corporation, under the terms of Contract DAAJ02-68-C-0001. It discusses the review of gas turbine engine bearing and seal technology conducted in conjunction with the ST9 Demonstrator Engine program.

The objectives of this portion of the contractual effort were (1) to conduct a design review of advanced technology bearing and seal package concepts for large engines to determine which concepts might be applicable to small engines, (2) to determine suitable scale factors from large bearing and seal technology to small engine applications, (3) to recommend systematic test programs to provide scale factor data where scale factors are in question, and (4) to determine what bearing and seal technology is lacking for advanced small engines.

In general, the above objectives were met and are presented in this report.

Appropriate technical personnel of this Directorate have reviewed this report and concur with the conclusions and recommendations contained herein. The Eustis Directorate project engineer for this effort was David B. Cale, Propulsion Division.

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Final Report

by

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SUMMARY

Pratt & Whitney Aircraft large and small engine main shaft bearings and seals were reviewed (1) to identify large gas turbine engine bearing and seal concepts or characteristics which are applicable to small gas turbine engines of the 2-10 lb/sec airflow size, (2) to define large engine bearing and seal design standards for applicability to small gas turbine engines, (3) to determine suitable factors for scaling bearing and seal technology concepts from large gas turbine engines to small, 2-10 lb/sec airflow size turbine engines, (4) to recommend test programs to provide scaling data where scale factors are questionable, and (5) to determine what bearing and seal technology is lacking for advanced small engines.

To accomplish this task, bearing and seal characteristics that might define standard design practices or scale factors were selected. After collection and compilation of pertinent data, comparisons were made to establish relationships between engine size and selected bearing and seal characteristics. In addition, comparisons of selected characteristics of large, mostly twin-spool engines versus small engine bearing, seal, and rotor dynamic characteristics were made.

As a result, scale factors were obtained between total corrected airflow into the engine and several low rotor ball bearing characteristics. Similarly, high rotor roller bearings were found to scale with corrected airflow into the high compressor. In general, bearing and seal size was found to increase with engine size.

Although scale factors were obtained, their utilization should be confined to preliminary design only. This recommendation is made because of the many areas which can affect bearing design.

Several research programs are recommended to provide bearing and seal technology which is lacking for advanced engines. These programs include areas such as advanced bearing and seal analysis programs as well as seal wear and roller dynamics studies.

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LIST OF SYMBOLS

d = element diameter

D_m = pitch diameter

n = number of elements

ℓ = roller length

N = shaft speed in rpm

D = bore diameter in mm

p = seal face pressure in psi

ΔP = pressure gradient across seal face in psi

V = rubbing velocity in ft/sec

COLLECTION AND COMPILATION OF DATA

Existing bearings and shaft seals of three small gas turbine engines (PT6A-27, JT12, and ST9) and six large engines (JT3D, JT8D, JT9D, TF30 P100, JTF20, and JTF22) were reviewed. In cases of multiple engine versions, efforts were made to utilize latest designs.

A survey of bearing and seal characteristics was made to ensure collection of essential bearing and seal data as quickly as possible. As a result, prints were accumulated for each engine bearing and seal. These prints or drawings contain essential design information for vendor coordination and company reference.

Also, several characteristics were found to be common to small and large engine bearings and seals. These characteristics often change with flight conditions. For this reason, sea level takeoff (SLTO) was selected as the basic flight point to analyze, because it is a common flight performance point shared by all engines.

The following data common to small and large engine bearings were accumulated for each engine bearing:

1. Operating Clearance or Contact Angle at SLTO

   Bearings are designed to operate with a definite amount of looseness or diametral internal clearance. For roller bearings, this radial or diametral internal clearance is usually a nominal 0.0005 in. to 0.0015 in. Main shaft ball bearings are normally split-race, angular contact bearings because of extra capacity, easy assembly, and freedom to employ a one-piece cage. Ball bearings are usually designed to operate at a contact angle range of 15 deg to 30 deg depending on speed, load, thermal environment, and life requirements. Operating clearance or contact angle is one of the most important design characteristics of a bearing, since it influences contact stresses, deflections, load distribution, and fatigue life.

2. Methods of Lubrication and Cooling

   Since bearings separate rotating and stationary structures, friction and wear from the relative motion of metallic surfaces must be minimized. Methods of lubrication and cooling are extremely important and prevent metal-to-metal contact by establishing an oil film and by removing heat generated.

   There are three basic methods of lubricating and cooling bearings: (1) oil mist, (2) direct oil jet, and (3) under-race slots with optional oil holes at split race of ball bearings or at corner relief of roller bearings. For each bearing application, the method of lubricating and cooling must be optimized to ensure successful operation for extended periods of time. This optimization study must consider loads, speeds, sizes, environmental conditions, cost, and lubricant type.

3. Bearing Oil-Inlet Temperature at SLTO

Oil-inlet temperatures directly affect absolute values of race temperatures, because the removal of heat generated at the contact zone of the bearing is reduced as oil temperatures increase.

Lubricant properties are greatly affected by bearing temperatures. Temperatures influence oil viscosity, which is directly related to oil film thickness at the rolling element-raceway contact area. Oil film thickness must be greater than surface asperities, or surface distress will occur. Therefore, oil inlet temperatures have been controlled to provide sufficient oil film thickness. Oil inlet temperatures have been maintained between 180° F and 300° F.

4. Bearing Race Temperatures at SLTO

Race temperatures are extremely important for design purposes. The principal use is for calculating the change in bearing internal clearance to establish operating contact angle or internal clearance. Accuracy of analytically calculated race temperatures is, therefore, of utmost importance.

Although oil inlet temperatures are constant in the majority of the engines, race temperatures differ because of variations in bearing size, loads, speeds, and lubrication methods. Inlet oil temperature is the principal influence on the magnitude of race temperatures.

The lubrication properties of oil are greatly affected by bearing temperatures. Temperatures influence oil viscosity that is directly related to oil film thickness at the rolling element-raceway contact area. Oil film thickness, by necessity, must be greater than surface asperities, or surface distress will occur. Therefore, oil inlet temperatures must be controlled to provide sufficient oil film thickness. Race temperatures also affect the change in internal clearance of a bearing during operation; accuracy of analytically calculated race temperature is, therefore, of utmost importance. For this reason, analytical methods are constantly being updated to relate the effects of bearing loads, speed, size, and oil inlet temperatures.

Rig testing various size bearings under a wide range of loads, speeds, lubricants, and lubricant temperatures has provided inner and outer race temperature data. These data, coupled with a dimensionless heat transfer analysis, which considers friction, oil churning, and viscous drag, have established a prediction system for determining race temperatures. This prediction system is scalable to the extent that expected heat generation for small or large bearings is determined from previous small or large bearing rig testing.

5. Radial Loads (1 g and rotor response loads at SLTO)

Rotor, disc, and blade weights must be supported by bearings and passed on to the supporting structure. These loads are caused by gravity and are called "g" loads.

Although rotors are dynamically balanced before operation, a zero unbalance can never be achieved. Furthermore, discs slip on the shaft during operation and cause additional unbalance. The resulting radial loads caused by shaft unbalance are called rotor response loads and must be supported by bearings and housing structures.

Response and gravity loads must be anticipated during design to evaluate their effects on bearing life.

6 Maximum Maneuver Loads

When an airplane undergoes a maneuver condition, large radial loads result from gyroscopic moments. These radial loads are called maneuver loads. They must be transferred through the bearings to the supporting structure of the bearings. In such cases, bearings are required to structurally withstand resulting maneuver loads without fracture or permanent indentation.

Maneuver loads are functions of engine speed and shaft inertia, which are governed by engine design requirements. For example, commercial planes are often required to maneuver through a 1-rad/sec turn without engine failure; stiffer requirements, such as a 3-1/2-rad/sec maneuver, are sometimes imposed in military applications. In such cases, bearings are required to structurally withstand resulting maneuver loads without fracturing.

Small engine bearings have lower maneuver load requirements than large engine bearings. With this exception, no correlation between engine size (corrected airflow) and bearing maneuver load was found.

7. Preloaded Bearings

High-speed ball or roller bearings, which have small anticipated thrust or radial loads, respectively, are generally preloaded. Preloading is required to ensure a minimum contact load to prevent the bearing elements from sliding or skidding.

Method of preloading is constant regardless of engine size. A duplex-mounted ball bearing and an out-of-round outer race roller bearing are utilized to obtain preload in engines. The amount of preload is variable and depends on bearing size and engine duty cycle requirements which affect speeds and loads. The amount of preload cannot be directly scaled for this reason.

Analysis techniques are utilized to predict the amount of preload necessary to prevent skidding. The same analytical relationships are used for determining proper preload for engine bearings regardless of size. Techniques consider bearing size, loads, speeds, lubricant temperature, and roller bearing flexible structure.

8. Bearing Thrust Load at SLTO

Pressure gradients across compressor blades, turbine blades, and labyrinth seals result in axial shaft loads or ball bearing thrust loads. Definite pressure gradients are required throughout the engine for cooling purposes, engine thrust, and minimum shaft thrust load to prevent ball bearing skid.

Thrust loads affect bearing life and internal kinematics. For this reason, proper bearing thrust load is an important design consideration. Bearing thrust loads cannot be scaled, since minimum thrust load to prevent skid and maximum thrust load to obtain satisfactory life must be determined for each bearing application.

These data are presented in Tables I through IX.

The following standard design practices can be defined from these data:

a. Roller bearings are designed with a nominal internal operating clearance of 0.0005 in. to 0.00015 in.

b. Split-race, angular contact ball bearings are usually designed to operate at a contact range of 15 deg to 30 deg.

c. Bearing oil-inlet temperatures have been maintained between 180°F and 300°F.

d. Race temperatures are primarily dependent on oil inlet temperature.

e. Maneuver loads are functions of engine speed and shaft inertia, which are governed by engine duty cycle requirements.

f. Method of preloading bearings in engines is constant regardless of engine size. A duplex-mounted ball bearing and an out-of-round outer race roller bearing are utilized to obtain preload in an engine. Amount of preload is not constant but is dependent on size and duty cycle requirements.

g. Sufficient thrust load must be applied to high-speed ball bearings to prevent skid.

Similarly, the following data common to small and large engine seals were accumulated for each engine seal:

1. Pressure Gradient at SLTO and Pressure Gradient Range

   The chief purpose of shaft seals is to prevent the bearing compartment lubricant from leaking into the engine airpath. Air pressures surrounding a bearing compartment are designed to be greater than pressures inside the compartment. This prevents oil from being blown out of the compartment while complementing the sealing force of the seal. Pressure gradient at SLTO has been below 100 psi.

   Pressure gradient range is an important seal design factor, since the pressure gradient must be large enough to prevent oil leaks and also small enough to eliminate excessive sealing force, which causes large seal wear.

2. Methods of Lubrication and Cooling

   Compartment oil is normally utilized to remove frictional heat generated at the seal plate - seal face surface. At high rubbing velocities, tremendous wear may occur unless the seal rubbing surface is lubricated.

   Three basic methods of lubricating and cooling seals are: (1) oil mist or oil jet directed at seal plate, (2) oil holes in seal plate for cooling and oil mist for lubrication, and (3) oil holes in seal plate for cooling and at the rubbing surface for lubrication. For each application, the methods of lubrication and cooling are optimized to ensure smooth seal operation for extended periods of time. Rubbing speeds, pressure gradient range, and thermal environment must be examined to provide proper cooling and lubrication.

3. Seal Air Temperature at SLTO

   One of the principal environmental considerations in seal design is the temperature of the air surrounding the bearing compartment. Air temperature is usually greater than the bearing compartment temperatures and must be sealed out to prevent excessive oil temperatures. At the present time, air temperatures, where possible, are maintained below 1000°F.

4. Seal Spring Load

   To ensure sealing during all flight conditions including low pressure gradient points, face pressure is maintained by a spring. (This spring load is specified in terms of load per inch of seal face mean or pitch diameter.) A constant spring load per inch of diameter has been established from past experience for most seal applications. This is independent of engine size.

These data are shown in Tables X through XVII.

The following standard design practices can be defined from these data:

1. Pressure gradient at SLTO has been maintained below 100 psi.

2. Seal air temperatures have been maintained below 1000° F, where possible.

3. Spring load per inch of diameter is constant, regardless of engine size.

This compilation of general data laid the foundations for selection of bearing and seal characteristics common to both large and small engines.

In all, 48 bearing and 42 seal positions in nine gas turbine engines were examined. Also, separate manufacturers or vendors for each bearing position were considered; this resulted in an examination of 92 bearings.

The accumulation of general bearing and seal data resulted in a selection from prints of characteristics common to both large and small engine bearings and seals. As a result, the following bearing characteristics were collected for each engine bearing:

1. Envelope dimensions
    a. Inner diameter or bore diameter
    b. Outer diameter
    c. Width of inner raceway
    d. Width of outer raceway
2. Bearing type
3. Element number or complement
4. Element size
    a. Diameter
    b. Length
    c. Flat length
    d. Crown radius

e. Crown drop

f. Gage point for crown drop measurement

g. Corner radius

5. Pitch diameter

6. Ball bearing - inner and outer raceway curvatures

7. Cage type

8. Roller ℓ/d (ratio of roller length to diameter)

Figures 1 through 3 illustrate the above characteristics.

Many of these characteristics are specified in Tables XVIII through XXVI.

Similarly, the following characteristics were obtained for each engine seal:

1. Seal type
2. Pitch diameter
3. Face width
4. Nose width
5. Pressure balance ratio
6. Secondary seal type
7. Method of spring loading

Many of these characteristics are presented in Tables XXVII through XXXIV.

This review resulted in the accumulation of 1656 characteristics for the 92 bearings and 294 characteristics for the 42 seals.

The following engine performance and rotor dynamic characteristics possibly related to bearing and seal design were gathered:

1. Corrected airflow into the engine and high compressor at SLTO

   (Corrected airflow is defined mathematically as: Corrected Airflow = $\omega_a\sqrt{\theta}/\delta$, where ω_a is the physical inlet airflow in lb/sec (pps), θ is the ratio of the temperature at a specific engine location to the temperature on a standard day, and δ is the ratio of the pressure at a specific engine location to the pressure on a standard day.)

2. Rotor speed at SLTO

3. Shaft critical speeds

4. Damped bearings

5. Engine design life

6. Engine thrust with and without augmentation at SLTO

7. Engine weight with and without augmenter

8. Thrust specific fuel consumption (tsfc) with and without augmentation at SLTO

   (tsfc is defined by: tsfc = ω_F/T_F, where ω_F is the fuel flow in lb/hr and T_F is the net thrust in lb_f.)

9. Engine thrust to weight ratio at SLTO

10. Maximum compressor blade tip speed

These engine performance and rotor dynamic characteristics are shown in Table XXXV.

After basic bearing and seal characteristics were obtained from prints, additional parameters that gage bearing and seal performance were calculated. These parameters were selected because of the possibility of defining standard design practices or scale factors.

It was felt that scale factors, if existent, would have to be functions of parameters that are common to bearing and seal designers. Concentrated efforts were applied to establish scale factors for common design parameters.

Simple computer programs were written to calculate the following design and performance characteristics common to both large and small engine bearings and seals:

1. Dynamic capacity is that constant radial load which a group of apparently identical bearings with stationary outer ring can endure for one million inner ring revolutions without fatigue.

2. Approximate bearing weight.

3. DN is the product of the bearing bore in millimeters times the maximum shaft speed in rpm; this parameter serves as a guide for limiting shaft speed or bearing bore. It is a measure of the relative motion of the bearing with respect to the engine axis.

4. Element rotational speed is the speed of the ball or roller about the element axis of rotation.

5. Element-to-cage sliding velocity is the velocity of the element with respect to the cage.

6. Cage-to-guiding surface sliding velocity is the velocity of the cage relative to the guiding raceway.

7. D_mN is the product of the pitch diameter and shaft speed. Similar to DN, it is a measure of the motion of the pitch circle of the bearing relative to the engine axis.

8. d/D_m is the ratio of the element diameter to the pitch diameter. This is basically a differentiation of bearing series.

9. nd^2 or $nd\ell$ is the product of the number of elements or complement, element diameter, and the element length or diameter depending on bearing type. This is a relative measure of bearing capacity.

10. Roller ℓ/d is the ratio of the length to diameter of the element of a roller bearing. This is an intrinsic characteristic of each roller bearing. This parameter is related to capacity as well as optimized bearing dynamics.

11. Pitch-line velocity is the velocity of the cage and rolling elements relative to the bearing axis of rotation.

12. Element centrifugal load is the radial force created by the motion of the elements about the bearing axis of rotation.

13. Maximum element centrifugal load-induced stress is the maximum contact stress caused by element centrifugal load.

14. The rpm for constant centrifugal load-induced stress is the shaft speed required to produce a constant contact stress due to element centrifugal load.

15. Fatigue life is the number of hours at specific load and speed conditions that 90% of a group of bearings will complete before evidence of fatigue develops. This is an important design factor, since engine requirements usually dictate bearing life and, hence, affect bearing size.

16. Face sliding or rubbing velocity is the velocity of the seal face relative to the seal runner. This is a gauge of limiting seal speed and size.

17. ΔPV value is the product of the pressure gradient across the seal and the rubbing velocity. This is a measure of seal capability.

18. PV value is the product of the seal face pressure and seal rubbing velocity.

19. Face pressure due to spring load is the seal face pressure caused by spring load.

20. Total face pressure is the sum of the seal face pressures due to spring force and pressure gradients.

21. Spring force per inch of diameter is the ratio of the total spring force to the pitch diameter of the seal face.

These characteristics are specified in Tables XXXVI through XXXVIII.

Collected and calculated bearing and seal parameters totaled 3036 for the 92 bearings and 840 for the 42 seals.

COMPARISONS

An extensive study was made to establish possible relationships between engine size and selected bearing and seal characteristics. To relate engine size to bearing and seal design, the following performance characteristics were examined:

1. Engine thrust at sea level takeoff
2. Engine thrust-to-weight ratio at sea level takeoff
3. Thrust specific fuel consumption at sea level takeoff
4. Maximum compressor blade tip speed
5. Corrected engine airflow at sea level takeoff
6. Specific inlet airflow (ratio of total corrected inlet airflow to inlet area)

Except for corrected engine airflow, correlations were not obtained. This was attributed to the differences in duty cycle and engine augmentation requirements, which considerably affect engine thrust, thrust-to-weight ratio, and thrust specific fuel consumption. Maximum compressor blade tip speed for axial flow compressors and specific inlet airflow are nearly constant.

Total corrected airflow into the engine was compared with the following selected bearing characteristics: bore diameter, bearing DN, approximate bearing weight, D_mN, nd^2 or $nd\ell$, d/D_m, element centrifugal load, maximum stress caused by element centrifugal load, and rpm for constant centrifugal load induced stress.

Comparison of bore diameter vs total corrected airflow into the engine (Figure 4) showed that low rotor ball bearings increase in size with increased engine size or airflow.

A straight line relationship was obtained between total corrected airflow into the engine and low rotor ball bearing nd^2, a measure of bearing capacity (Figure 5). This linear equation exhibited an increase in ball bearing nd^2 with engine size. These relationships were valid for all engines except one large engine (the JT9D) and the two small engines with centrifugal compressors (the PT6A-27, and ST9). Similarly, approximate low rotor ball bearing weight was found to increase with total corrected engine airflow.

The principal result of these comparisons was that low rotor ball bearings increase in size linearly with engine size.

Comparisons between corrected airflow into the high compressor and selected high rotor bearing characteristics were also made. The three small engines (PT6A-27, JT12, and ST9) were not included in the comparisons, since these engines either do not have high compressors or have centrifugal compressors.

The general result of the comparisons was an expected increase in high rotor roller bearing size, bore diameter, approximate roller bearing weight, and roller centrifugal load with increasing corrected airflow into the high compressor.

Figure 6 shows the increase in high rotor roller bearing bore diameter with corrected airflow into the high compressor. A linear relationship was obtained. Other comparisons failed to show significant correlations.

The total corrected airflow into the engine and into the high compressor was compared with the following selected low and high rotor seal characteristics: pitch diameter, pressure gradient, seal air temperature, face sliding velocity, PV value, and pressure gradient range.

These comparisons showed that seal pitch diameter has generally increased with increasing corrected airflow into the fan and high compressor. (See Figures 7 and 8.) Hence, seals, like bearings, were found to increase with engine size.

Seal rubbing velocity, a relative measure of seal operating severity, and PV value have increased in magnitude with improved seal technology and engine requirements. Other correlations were not obtained.

The following selected characteristics of large vs small engine bearings were analyzed:

1. Bore diameter vs shaft speed, pitch line velocity, and pitch diameter
2. Element rotational velocity vs pitch diameter
3. DN vs D_mN, method of cooling, and method of lubrication
4. Pitch diameter vs element diameter, nd^2 or $nd\ell$ maximum stress developed by centrifugal load, and rpm for constant centrifugal load induced stress
5. Element-to-cage sliding velocity vs pitch diameter
6. Cage-to-guiding surface sliding velocity vs pitch diameter and $d/D_m \cos\alpha$ (where α is mounted contact angle)
7. Shaft speed vs d/D_m, roller ℓ/d, method of cooling, and method of lubrication
8. D_mN vs roller ℓ/d
9. d/D_m vs nd^2 or $nd\ell$
10. D_m vs d/D_m
11. nd^2 or $nd\ell$ vs maximum stress developed by centrifugal load and rpm for constant centrifugal load induced stress

12. Element diameter vs maximum stress developed by centrifugal load and rpm for constant centrifugal load induced stress

Correlations were found in some comparisons as listed and discussed below:

1. DN experience curve for main shaft bearings at sea level takeoff is shown in the comparison of bore diameter vs inner race speed (Figure 9).

2. Element rotational speed vs pitch diameter (Figures 10, 11 and 12) separated into three distinct bands: low rotor bearings, high rotor ball bearings, and high rotor roller bearings.

   Element rotational speeds of some large engine bearings were equal to those of small engine bearings. For this reason, small and large engine bearings were indistinguishable, except by the magnitude of the bearing pitch diameter.

   In each band, element rotational speed was found to generally increase as pitch diameter decreased. This was expected, since shaft speeds generally increase as engine size and bearing size decrease.

   For constant pitch diameter, element rotational speed was greater for high rotor roller bearings than ball bearings.

3. All bearings were contained in a definite band in a comparison of pitch diameter vs bore diameter. (See Figure 13.)

   A reference line was drawn through the points; an additional line was drawn at 45 deg to represent the theoretical case where pitch diameter would equal bore diameter. The distance between lines represented the bearing cross section thickness and shows a 15% greater increase than the bore diameter.

4. Comparison of pitch diameter with nd^2 and $nd\ell$ exhibited increased bearing capacity with increased pitch diameter. (See Figures 14 and 15.) This was expected, since a larger pitch diameter allows more space for an increase in the bearing complement, the element diameter, or both.

5. Comparison of D_mN vs d/D_m separated into two bands, one for roller bearings and one for ball bearings. The majority of roller bearings, regardless of engine size or shaft location, were bounded between d/D_m of 0.075 and 0.11, as shown in Figure 16. Similarly, the a majority of the ball bearings were bounded between d/D_m of 0.115 and 0.14, as shown in Figure 17.

6. Roller L/D ratio has been principally designed between 0.95 and 1.20. As shown in Figure 18, almost 50% of all rollers studied had an L/D ratio between 0.95 and 1.00.

7. Design limit on bearing cooling and lubrication by oil mist vs positive methods, such as direct jet or under race oil slots, was constant.

Other comparisons failed to show significant correlations.

The following selected characteristics of large vs small engine seals were compared:

1. Pressure balance ratio vs pitch diameter

2. Face pressure caused by spring load vs pitch diameter

3. Total face pressure vs pitch diameter

4. Spring load vs pitch diameter

5. Face pressure caused by spring load vs face sliding velocity

6. Face sliding velocity vs total face pressure, method of cooling, method of lubrication, and pressure gradient

7. Face width vs pitch diameter

8. Pressure gradient vs pitch diameter, method of cooling, and method of lubrication

9. Spring force/in. of diameter vs pressure gradient

10. Pitch diameter vs shaft speed and PV value

11. Shaft speed vs spring force/in. of diameter

12. Pressure gradient range vs method of cooling and method of lubrication

Results of the comparisons were:

1. Face rubbing velocity vs total face pressure and pressure gradient vs pitch diameter (Figures 19 and 20, respectively) showed a wide band of points with a tendency to increase. Due to the width of these bands, no exact correlations could be made.

2. Design limit on seal plate cooling and lubrication by oil mist, as opposed to positive methods, was constant.

3. Pressure balance ratio, seal face width, seal nose width, and spring force/in. of diameter were constant regardless of engine size. Other significant results were not obtained.

ROTOR DYNAMIC CHARACTERISTICS

In addition to defining standard design practices, large vs small engine rotor dynamic characteristics listed and discussed below were evaluated for possible relationships.

BEARINGS PER SHAFT

In general, long engines have three bearings per shaft and several intershaft bearings; shorter engines have either two or three bearings per shaft. The present trend in shaft dynamics is to have two bearings per shaft. More than two bearings can result in shaft alignment problems.

During engine design, the exact number of bearings required is determined by a thorough critical speed analysis.

ENGINE CRITICAL SPEEDS

All new engine rotor designs are analyzed with realistic support and case structures using critical speed analysis with strain energy consideration. The purpose of the analysis is to obtain shaft critical speeds and rotor response.

Critical speed analysis is dependent on shaft stiffness, bearing stiffness, bearing location, and number of bearings, as well as disc, shaft, and blade inertias. For this reason, past attempts to relate shaft critical speed or shaft sensitivity of one engine to another have failed. A possible relationship between shaft sensitivity and shaft speed to weight ratio may exist, but extensive vibration and rotor dynamic studies would be required to define this relationship.

New engines have a greater shaft slenderness (length to diameter) ratio compared to old engines. For this reason alone, critical speeds are not scalable.

DAMPED BEARINGS

When critical speeds occur within the flight envelope, bearing response loads can become large. To design out of the critical speed region, bearing supports are usually "softened." This reduces shaft critical speed below flight speed requirements. The shaft can then accelerate through the critical speed mode without vibration problems.

To provide softer supports, damped bearings are utilized. Methods of damping are constant. Roller bearings are oil-damped or floated on a thin film of oil. Ball bearings are designed with a "hairspring" support or a "hairspring" oil film combination. Expert structural and bearing design is required to establish manufacturing, deflection, stress, and raceway ovalization limitations.

The necessity for damped bearings has been principally created by the shaft sensitivity of advanced small, high-speed engines. This is because damped bearing requirements are related to shaft sensitivity caused by (1) rotating unbalance, (2) shaft speed to weight ratio, and (3) shaft strain energy. A comprehensive vibration analysis would be required to establish firm relationships.

INVESTIGATION OF SCALE FACTORS

Low rotor ball bearings were found to scale with total corrected airflow into the engine; similarly, high rotor roller bearings scaled with corrected airflow into the high compressor. Scale factors were found applicable to conventional engine designs with axial flow compressors.

Scale factors were established by obtaining ratios of selected bearing and seal characteristics vs ratios of engine airflow. Sea level takeoff was chosen as the operating condition because it is common to all engines. The purpose of the ratios was to graphically establish linear or polynomial relationships between selected bearing and seal characteristics of large and small engines. Scale factors could then be formulated as the slopes of resulting straight or bounding lines.

A simple computer program was written to calculate and tabulate the ratios of selected bearing and seal characteristics for the study engines at sea level takeoff. Ratios were obtained with respect to ST9 bearing and seal characteristics; but regardless of which engine was used as a basis, the ratios would have remained in the same relative positions.

The ST9 and PT6A-27 engines have power turbine and gas generator shafts instead of the usual low and high rotor shafts. Because of speed and size, the power turbine shafts were considered as low rotor shafts. For similar reasons, the gas generator shafts were considered as high rotor shafts.

To ratio bearing and seal characteristics, a ball and a roller bearing were needed for each shaft. The ST9 power turbine shaft has three bearings (single and duplex ball bearings and one roller bearing); the gas generator shaft has a ball and a roller bearing. The No. 2 duplex-mounted ball bearing (engine bearing order is established by progressive numbers from front of engine) was designed to provide engine maintainability, to alleviate critical speed problems, to support installation loads, and to locate the power drive shaft. These specialized purposes made scaling impractical. Hence, the No. 2 bearing was not utilized to obtain low rotor ball bearing ratios in the analysis.

Earlier studies tried to establish relationships between engine size and selected bearing and seal characteristics. Except for corrected airflow, correlations between bearing and seal selection and engine size were not obtained. In a study to establish scale factors between engine size and selected bearing and seal characteristics, only corrected airflow was considered. The total corrected airflow ratio was compared with the following ratios: bearing bore diameter, nd^2 or $nd\ell$, bearing weight, bearing capacity, d/D_m, DN, D_mN, pitch diameter, element diameter, pitch-line velocity, centrifugal load, element rotational speed, element-to-cage rubbing velocity, cage-to-land rubbing velocity, ratio of maximum stress developed by centrifugal load, and rpm ratio from constant centrifugal load induced stress.

Ratios of selected bearing characteristics (D_mN, pitch line, element rotational speed, element-to-cage rubbing velocity, and cage-to-land rubbing velocity) were found to generally decrease with increasing airflow ratios.

These comparisons substantiated expectations that bearing speeds generally decrease with increasing engine size or airflow.

Good correlations between total corrected airflow and bore diameter, nd^2, and pitch diameter ratios were obtained for low rotor ball bearings. (See Figures 21, 22, and 23.)

The linear relationships coincided with previous results that low rotor ball bearing size has increased with increased engine size or corrected airflow; furthermore, scale factors were established between certain low rotor ball bearing characteristics and engine size. These scale factors are defined below:

$$\text{Bore diameter (mm)} = 0.11 \text{ (total corrected airflow in lb/sec)} + 79.2 \quad (1)$$

$$nd^2 \text{ (sq in.)} = 0.018 \text{ (total corrected airflow in lb/sec)} + 6.09 \quad (2)$$

$$\text{Pitch diameter (in.)} = 0.0054 \text{ (total corrected airflow in lb/sec)} + 3.99 \quad (3)$$

The average deviation for these equations is 3%.

Low rotor ball bearings of the JT9D engine and the two engines with centrifugal compressors, the PT6A-27 and the ST9, failed to satisfy the scale factor relationships.

Two bands, one for ball bearings and one for roller bearings, were obtained for d/D_m ratios regardless of the comparison. (See Figures 24 and 25.) These graphs coincide with previous results that d/D_m separates into distinct bands for the majority of the ball and roller bearings.

Similarly, relationships between the corrected airflow into the high compressor and ratios of selected high rotor bearing characteristics were investigated. The TF30 P100 engine was utilized as a basis to ratio selected high rotor bearing and seal characteristics. This was similar to utilization of the ST9 engine as a basis for establishing scale factors between total corrected airflow into the engine and selected bearing and seal characteristics. The TF30 P100 engine was chosen because of its lower value of corrected airflow into the high compressor vs other engines with high compressors. The three small engines (PT6A-27, JT12, and ST9) were disregarded in the analysis, since these engines either do not have high compressors or have centrifugal compressors.

Certain ratios (bore diameter, weight, $nd\ell$, pitch diameter, and element diameter) of high rotor roller bearing characteristics were found to increase with increasing corrected airflow into the high compressor. (See Figures 26 through 29.)

Results paralleled those obtained previously for low rotor ball bearings. Again, expectations that bearing size had increased with engine size were substantiated.

The straight lines of these comparisons established scale factors between certain high rotor roller bearing characteristics and engine size. These scale factors are defined below:

Bore diameter (mm) = 1.12 (corrected airflow into high compressor in lb/sec) + 92.3 (4)

$nd\ell$ (sq in.) = 0.189 (corrected airflow into high compressor in lb/sec) + 1.23 (5)

Pitch diameter (in.) = 0.049 (corrected airflow into high compressor in lb/sec) + 4.56 (6)

Element diameter (in.) = 0.0043 (corrected airflow into high compressor in lb/sec) + 0.35 (7)

Scaling equations are accurate within an average deviation of 6%.

An investigation was made to determine the possibility that the two small engines with centrifugal compressors might scale like large engines with axial compressors. The ST9 was chosen to compare with the large engines, and its centrifugal compressor was treated as a high compressor. ST9 bearings, however, failed to scale like the large engine bearings.

Using the ST9 as a basis, comparisons were made between the total corrected airflow into the engine and the following selected seal characteristic ratios: pitch diameter, pressure gradient, seal air temperature, seal rubbing velocity, seal PV value, pressure gradient range, spring force ratio, total face pressure, and face pressure caused by spring load ratio.

Comparisons showed that seal pitch diameter ratio increased with increasing total corrected airflow. This result confirmed initial expectations that seal size has increased with engine size. Scale factors were not obtained because upper and lower bounds for the data points could not be established. Other comparisons failed to show significant trends.

Similarly, comparisons between the corrected airflow into the high compressor and ratios of selected high rotor seal characteristics were made with the TF30 P100 as a basis.

Except for the expected trend for seal pitch diameter to increase with engine size, correlations were not obtained. Again, scale factors were impossible to obtain because of the difficulty in establishing upper and lower bounds.

The scalability study continued with an investigation to ascertain scale factors for selected characteristics of large vs small bearings and seals. Again, the ST9 bearings and seals were utilized as a basis to obtain ratios.

The following ratios of selected characteristics of large vs small engine bearings were analyzed:

1. Pitch diameter vs element rotational speed ratio, element diameter ratio, nd^2 or $nd\ell$ ratio, element-to-cage rubbing velocity ratio, cage-to-land rubbing velocity ratio, ratio of maximum stress developed by centrifugal load, and rpm ratio for constant centrifugal load induced stress

2. Bore diameter vs pitch line velocity ratio and pitch diameter ratio

3. d/D_m vs nd^2 or $nd\ell$ ratio

4. D_mN vs d/D_m ratio

5. DN vs d/D_m ratio

6. nd^2 or $nd\ell$ vs ratio of maximum stress developed by centrifugal load and rpm ratio for constant centrifugal load induced stress

7. Element diameter vs ratio of maximum stress developed by centrifugal load and rpm ratio for constant centrifugal load induced stress

Correlation was found in some comparisons as listed and discussed below:

1. The graph of pitch diameter vs element diameter ratio exhibited expected increasing element size for increasing pitch diameter

2. Comparisons of pitch diameter vs nd^2 ratio for low rotor ball bearings or $nd\ell$ ratio for roller bearings showed expected increasing element number and size for increasing pitch diameter. (See Figures 30 and 31.)

   Equations were derived to describe the relationships:

   $$nd^2 \text{ (sq in.)} = 0.0196 \text{ (pitch diameter)}^3 + 0.1236 \text{ (pitch diameter)}^2 + 0.40 \text{ (pitch diameter)} + 1.29, \tag{8}$$
   for low rotor ball bearings (where units for pitch diameter are in.)

   $$nd\ell \text{ (sq in.)} = 2.54 \text{ (pitch diameter in in.)} - 5.71, \tag{9}$$
   for upper boundary

   $$nd\ell \text{ (sq in.)} = 2.09 \text{ (pitch diameter in in.)} - 4.96, \tag{10}$$
   for lower boundary

3. Comparisons of pitch diameter ratio vs bore diameter established definite scale factors. These factors can be utilized in determining the cross-section thickness between the bearing bore and pitch diameters or in comparing a new design to past experience.

Ball bearings and low rotor roller bearings were contained in a definite band. (See Figure 32.) The boundaries are defined by:

Pitch diameter ratio = 0.348 (bore diameter) + 0.27, for upper boundary (11)

Pitch diameter ratio = 0.348 (bore diameter) + 0.11, for lower boundary (12)

From these bounds, individual equations for low rotor ball bearings, high rotor ball bearings, and low rotor roller bearings were obtained by conversion factors.

High rotor roller bearings formed a straight line which was lower than the band obtained for other bearings (Figure 33). The straight line is defined by:

$$\text{Pitch diameter ratio} = 0.332\ (\text{bore diameter}) + 0.10 \qquad (13)$$

By conversion factors, the equation becomes

$$\text{Pitch diameter (in.)} = 1.13\ (\text{bore diameter in in.}) + 0.35 \qquad (14)$$

The average of these equations established the straight line obtained previously between bearing bore and pitch diameters (Figure 13). The equation is:

$$\text{Pitch diameter (mm)} = 1.15\ (\text{bore diameter in mm}) + 8.9.$$

4. Pitch diameter vs element rotational speed ratio (Figures 34, 35, and 36) separated into three distinct bands: low rotor bearings, high rotor roller bearings, and high rotor ball bearings. Small and large engine bearings were distinguishable only by the magnitude of the pitch diameter. In general, the element rotational speed increased as the pitch diameter decreased. This was expected, since, as previously stated, shaft speeds have generally increased as engine and bearing sizes have decreased. Definite scale factors were not obtained because of the difficulty in establishing upper and lower bounds for these graphs.

In other comparisons, correlations were not obtained.

In addition, the following comparisons of ratios of selected characteristics of large vs small engine seals were made:

1. Pitch diameter vs spring force ratio, total force pressure ratio, face pressure caused by spring load ratio, pressure gradient range ratio, and seal PV value ratio

2. Ratio of face pressure due to spring load vs rubbing velocity ratio

3. Rubbing velocity ratio vs total face pressure ratio

Significant correlations were not obtained. Certain seal characteristics, such as pressure balance ratio, seal face width, seal nose width, and spring force/in. of diameter, were found to be nearly constant, regardless of engine size.

This concluded the 157 comparisons made to obtain scaling factors.

DISCUSSION OF SCALE FACTORS

Scale factors were found for low rotor ball bearings as a function of total corrected airflow into the engine. High rotor roller bearings were found to scale with corrected airflow into the high compressor. As anticipated, these results showed that bearing size has increased with engine size or airflow. However, the startling result of the scalability study was the remarkable linearity between the increase in bearing size with increased engine size.

Scale factors were found to be applicable to axial flow compressor engine designs, and not applicable to centrifugal compressor engine designs.

Questions arose as to why low rotor roller bearings and high rotor ball bearings did not scale. Considerable effort was required to finally uncover the answers.

Low rotor roller bearings are generally located at the front and rear of engines. The front roller bearing on conventionally designed engines, which do not have centrifugal compressors, has been sized so that a tool can be inserted inside the shaft. The tool is required to remove the tie bolt that connects the low turbine shaft to the low rotor.

At the rear of the engine, the roller bearing is sized to allow for an oil jet to the "bazooka" which "spirals" lubricant to intershaft bearings. In cases where there are no intershaft bearings, the bearing design is governed by two factors: (1) a straight-through shaft is designed to save manufacturing cost, and (2) to conserve weight, the rear of the shaft is made as small in diameter as possible.

High rotor ball bearings have been designed for two principal functions: to locate the main shaft accessory drive gear and to support high rotor thrust loads. Because of the variations in high rotor thrust loads coupled with engine life requirements, scalability of high rotor ball bearings is impractical.

The ultimate limitation on main-shaft bearing size is the airflow path, since neither bearings nor bearing compartments must obstruct the flow path.

The two small engines, the PT6A-27 and ST9, did not scale like the large engines and the JT12. Hence, investigations were made to explain the inapplicability of scale factors to small engines with centrifugal compressors.

The ST9 power turbine shaft roller bearing was designed to fit over the shaft optimized in size to satisfy critical speed requirements. As previously stated, the small 2-to-10-lb/sec airflow size engines rotate at considerably greater speeds than large engines. For this reason, bearing size in future small gas turbine engines will probably be governed by required shaft size to satisfy critical speed design criteria.

Thrust balancing the power turbine shaft of small engines is difficult because there is no compressor to counteract the turbine pressure loads. Because of this difficulty, low rotor ball bearings, which support power turbine shaft thrust loads, did not scale.

The gas generator shaft ball bearing is designed to locate the main shaft accessory drive gear and to support high rotor thrust loads. Bearing loads and engine life requirements usually define the bearing size.

Size of the gas generator shaft roller bearing is based on the shaft diameter required to satisfy critical speed design criteria and to provide clearance for power turbine shaft operation inside the gas generator shaft.

Hence, scale factors are only applicable to conventional engine designs, not to small gas turbine engines that have centrifugal compressors.

AREAS WHICH LIMIT THE UTILITY OF SCALE FACTORS

Areas exist that limit the utility of scaling factors. Scale factors obtained in the study are useful only as preliminary design guides and should be further restricted to engines without centrifugal compressors.

Rotor dynamic, performance, and design considerations listed below can limit scaling:

1. Outer race flanges
2. Manufacturing capabilities
3. Value engineering
4. Shaft torque
5. Weight reduction
6. Blade loss loads
7. Critical speed design criteria
8. Rotor response loads
9. Number of bearings per shaft
10. Fluid film damper
11. Airflow path
12. Preload design criteria
13. Maneuver loads
14. Duty cycle requirements
15. Gear and impeller locations
16. Life requirements
17. Shaft thrust loads

Because of factors such as fluid film dampers, bearings flanges, manufacture of a straight-through shaft to reduce cost, conservation of weight, and shaft torque, bearing size may be limited. Dampers reduce rotor response loads, thus reducing bearing size. However, the addition of a fluid film damper or of bearing flanges often dictates an increase in outer race stiffness or cross section.

Possible influence on bearing size can be exerted by bearing loads, such as blade loss loads, rotor response loads, preloads, and maneuvers loads, or by engine requirements, such as airflow path, critical speed design criteria, life, and number of bearings per shaft.

In additon, cooling and lubrication methods can be detrimental in determining bearing size. For instance, under-race oil holes sometimes result in larger than normal raceway thickness, preventing possible raceway fracture caused by heavy loads.

Similarly, corner-relief oil holes in roller bearings must be carefully analyzed to ensure that the raceway does not fracture and that oil holes will not "coke".

One of the latest recognized features in ball bearing cage design is the "elongated" ball pocket. This design concept provides for extreme ball excursion or the circumferential movement of a ball as it passes in and out of the load zone. In many cases, the extra ball pocket clearance means a reduction in the bearing complement to maintain sufficient cage web thickness for strength. The reduction in ball complement will also reduce the bearing capacity or, effectively, nd^2, if the ball diameter remains constant.

To reiterate, scale factors must be utilized with insight into the design concepts and limitations that can affect bearing design.

RECOMMENDED ADDITIONAL BEARING AND SEAL RESEARCH FOR ADVANCED SMALL ENGINES

There are several areas where bearing and seal technology is lacking or needs further development for advanced small engines. Where appropriate, tests to provide development of advanced technology are discussed.

BEARING MATERIAL IMPROVEMENT STUDY

Flanged bearings are demanded in modern gas turbine engines to reduce compartment or gearbox weight and to prevent outer race rotation within the housing. For this application, bearing materials would be required to have excellent structural properties to resist large bending moments and shear loads. In addition, excellent fatigue properties are needed to obtain long-life operation without surface or subsurface distress. Usual bearing materials provide adequate fatigue life. However, these materials are usually through-hardened steel and are quite notch sensitive. This high brittleness severely limits use in structural applications.

Metallurgists have developed new steels, but extensive tests are required to substantiate ultimate structural limits and, more importantly, to rate their mechanical capabilities, such as fatigue life and wear rate, as a function of oil film thickness to surface finish ratio.

To evaluate ultimate structural properties, bearing testing will be required. Essential structural designs that these tests must establish are: material rolling contact fatigue properties, maximum contact stress before plastic deformation and before fracture, maximum shear and maximum bending stress before fracture.

BALL BEARING CAGE STUDY

Several programs are needed to improve cage performance and predictability under adverse environments and operating conditions.

Flexible shafts create large bearing response loads that reduce ball bearing thrust to radial load ratio and cause large ball movement or excursion in the cage pocket. To counteract the resulting cage pocket wear, elongated pockets must be designed. Hence, analytical capabilities, which should include elastohydrodynamic effects, must be developed to predict ball excursions and the resulting ball loads when pocket clearances are inadequate. These analytical techniques must be correlated with test results by measuring the ball movements with the aid of a high-speed camera and the ball-cage web load with photoelastic methods.

CAGE CONFIGURATION AND VIBRATION STUDY

A program is needed to evaluate cage vibration and configurations. This program should include carefully controlled tests to establish tolerance requirements for cage pocket clearances, effects of cage vibration on various cage designs, and cage unbalance associated with cage speed, weight, journal width, clearance, and lubrication film thickness under journals.

ANALYTICAL BEARING PROGRAMS

Proven analytical methods combined with experience are the design tools for substantiating future bearing designs.

Present bearing analysis programs do not include bearing dynamic effects due to elastohydrodynamic forces. Future programs must include these forces that tests show affect bearing operation and durability.

Present elastohydrodynamic force equations do not include rheological or non-Newtonian effects. Further developments in this area are required. Resulting programs will require careful correlation with test results.

Principal areas where correlations must be established between analytical programs and experimental data include: (1) rolling element skid criteria, (2) rolling element-cage web load, (3) ball excursion, and (4) roller skew (the tendency of the roller to twist or turn from its neutral position).

ROLLER DYNAMICS STUDY

Roller end wear is a common problem with high-speed roller bearings. Theories, though unsuccessful, have been proposed to explain this phenomenon. An extensive test program will be required to fully explain the problem and confirm a solution.

Some parameters to study are: (1) sidewall height, (2) sidewall taper, (3) axial clearance between the roller end and sidewall, (4) relative velocity between the roller end and sidewall, (5) roller length variation, (6) roller unbalance, and (7) interaction effects with cages.

SEAL WEAR STUDY

The scalability study showed that shaft seals have increased with engine size and that pressure balance ratio, seal face and seal nose width, and spring force/in. of diameter have been constant. In addition, the type of secondary seal has usually been a piston ring because (1) they allow large axial travel caused by differential thermal growth, without restraining small motions of the primary seal while following runner irregularities, and (2) their cost is low.

Even though seal design has been constant, seal wear rate is unpredictable. For this reason, statistical seal wear studies, similar to previous bearing fatigue life studies, are needed. The effects on seal wear rates due to the following parameters must be closely established:

1. Seal air temperature
2. Face pressure
3. Rubbing velocity

4. Seal and runner materials

5. Pressure balance ratio

6. Seal size characteristics, such as pitch diameter, nose width, and face width

7. Lubrication or cooling methods

ANALYTICAL SEAL PROGRAMS STUDY

Analytical seal programs are needed to provide design guides for calculating (1) elastohydrodynamic effects at the seal face, (2) pressure profile at the seal face, and (3) more accurate seal leakage. Again, the analytical programs must be correlated with test or past seal performance data.

CONCLUSIONS

Twin-spool axial compressor engine designs have scalable low rotor ball bearings and high rotor roller bearings.

Valid scale factors exist for total corrected airflow vs several low rotor ball bearing characteristics and high rotor roller bearing characteristics. Remaining bearing characteristics were so dependent upon engine design and bearing location that scale factors were not practical.

There were no valid scale factors noted for seals. However, specific seal parameters such as pressure balance ratio, seal face width, seal nose width, and spring force per inch of diameter were found to be nearly constant.

Small gas turbine engines with centrifugal compressors do not scale like large twin-spool engines with axial compressors.

TABLE I. MAIN SHAFT BEARING GENERAL CHARACTERISTICS AT SEA LEVEL TAKEOFF FOR SMALL ENGINE NO. 1

Bearing Location	Bearing Type	Nominal Operating Clearance or Contact Angle	Method of Lubrication	Method of Cooling	Oil-in Temperature (°F)	Bearing Race Temperatures (°F)		Thrust Load (lb_f)	Radial Loads (lb_f)		(X) Fatigue Life (hr)
						Inner	Outer		Static (1 g)	Rotor Response Loads	
1.	Roller	0.001 in.	four corner relief oil holes	under-race	300	338	353	-	5.6	300	6150
2.	Ball	25 deg	oil holes in split inner race	under-race	300	340	376	125	1.8	80	9750
3.	Ball	23 deg	oil holes in split inner race	under-race	300	319	347	1560	33.6	55	850
4.	Roller	0.001 in.	oil mist	under-race	300	333	344	-	21	60	6155
5.	Roller	27 deg	oil holes in split inner race	under-race	300	322	399	1750	21	*	1230

*Value could not be obtained.
(X) Based on rotor response loads with life factor.

TABLE II. MAIN SHAFT BEARING GENERAL CHARACTERISTICS AT SEA LEVEL TAKEOFF FOR SMALL ENGINE NO. 2

Bearing Location	Bearing Type	Nominal Operating Clearance or Contact Angle	Method of Lubrication	Method of Cooling	Oil-in Temperature (°F)	Bearing-Race Temperatures (°F)		Thrust Load (lb_f)	Radial-Loads (lb_f)		X Maximum Maneuver Loads (lb_f)
						Inner	Outer		Static (1 g)	Rotor Response Loads	
1	Roller	0.0007 in.	jet	flood	195-210	325	300	-	40	*	432
2	Ball	29.5 deg	oil holes in inner race	under-race	195-210	300	325	1190	244	*	205
3	Roller	0.0007 in.	jet	flood	195-210	325	300	-	351	*	226

*Data not presently available

X 1 rad/sec load

TABLE III. MAIN SHAFT BEARING GENERAL CHARACTERISTICS AT SEA LEVEL TAKEOFF FOR SMALL ENGINE NO. 3

Bearing Location	Bearing Type	Nominal Operating Clearance or Contact Angle	Method of Lubrication	Method of Cooling	Oil-in Temperature (°F)	Bearing Race Temperatures (°F) Inner	Bearing Race Temperatures (°F) Outer	Thrust Load (lb_f)	Radial Loads (lb_f) Static (1 g)	Radial Loads (lb_f) Rotor Response Loads	ⓧ Maximum Maneuver Loads (lb_f)	** Fatigue Life (hr)
1	Ball	20 deg	oil slots in split inner race	lubricate also cools	200	300	250	450	10	✓ 70	290.5	1200
2	Roller	0.0015 in.	oil jet on each side aimed at cage inner ring clearance	lubricate also cools	200	425	375	-	20	✓ 650	290.5	-100,000
3	Roller	0.0015 in.	oil jet on each side aimed at cage inner ring clearance	lubricate also cools	200	400	350	-	14		262.5	+100,000
4	Ball	20 deg	oil slots in split inner race	lubricate also cools	200	330	280	450	2		262.5	1250

Legend

✓ 2nd stage compressor
Blade loss 1.7 oz-in. at 30,000 rpm
No structural damping

ⓧ 3-1/2 rad/sec
information lost

**Roller bearings evaluated at 5 g loads; Ball bearings evaluated at mean effective thrust loads of 450 lb; No material improvement factors

TABLE IV. MAIN SHAFT BEARING GENERAL CHARACTERISTICS AT SEA LEVEL TAKEOFF FOR LARGE ENGINE NO. 1

Bearing Location	Bearing Type	Nominal Operating Clearance or Contact Angle	Method of Lubrication	Method of Cooling	Oil-in Temperature (°F)	Bearing Race Temperatures (°F) Inner	Outer	Thrust Load (lbf)	Radial Loads (lb_f) Static (1 g)	Rotor Response Loads	X Maximum Maneuver Loads (lbf)
1	Roller	*	jet flood	jet flood	190-200	*	*	-	299	*	2931
2	Ball	*	flood	flood	190-200	*	*	4500	209	*	2931
2-1/2	Ball	*	jet mist	jet mist	190-200	*	*	366	6	*	**
3	Roller	*	jet flood	jet flood	190-200	*	*	-	241	*	3544
4	Ball	*	flood	flood	190-200	*	*	8100	192	*	2458
4-1/2	Roller	*	jet flood	jet flood	190-200	*	*	-	179	*	1832
5	Roller	*	flood	flood	190-200	*	*	-	325	*	1086
6	Roller	*			190-200	*	[illegible]	-	253	*	1832

*Data not presently available
**No calculated load available
X 1 rad/sec load

TABLE V. MAIN SHAFT BEARING GENERAL CHARACTERISTICS AT SEA LEVEL TAKEOFF FOR LARGE ENGINE NO. 2

Bearing Location	Bearing Type	Nominal Operating Clearance or Contact Angle	Method of Lubrication	Method of Cooling	Oil-in Temperature (°F)	Bearing Race Temperatures (°F)		Thrust Load (lbf)	Radial Loads (lbf)		(X) Maximum Maneuver Loads (lbf)
						Inner	Outer		Static (1 g)	Rotor Response Loads	
1	Roller	0.003 in.	oil mist	oil mist	240	250	300	-	120	*	2319
2	Ball	32 deg	oil holes in split inner race	oil holes in split inner race	240	300	325	2550	160	*	2319
3	Ball	15 to 20 deg	oil mist	under-race	240	350	350	400	200	*	2048
4	Ball	37 deg	oil holes in split inner race	oil holes in split inner race	240	350	375	2460	120	*	747
4-1/2	Roller	0.001 in.	flood oiled	flood oiled	240	400	400	-	120	*	954
5	Roller	0.001 in.	oil mist	under-race	240	350	375	-	250	*	1361
6	Roller	0.005 in.	oil mist	under-race	240	250	350	-	150	*	954

*Data not presently available

(X) 1 rad/sec load

TABLE VI. MAIN SHAFT BEARING GENERAL CHARACTERISTICS AT SEA LEVEL TAKEOFF FOR LARGE ENGINE NO. 3

Bearing Location	Bearing Type	Nominal Operating Clearance or Contact Angle	Method of Lubrication	Method of Cooling	Oil-in Temperature (°F)	Bearing Race Temperatures (°F)		Thrust Load (lb_f)	Radial Loads (lb_f)		X Maximum Maneuver Loads (lb_f)
						Inner	Outer		Static (1 g)	Rotor Response Loads	
1	Ball	31 deg	oil holes in split inner race	under-race	180-200	250	350	16,600	1300	*	6500
2	Ball	36.5 deg	oil mist	under-race	180-200	220	270	10,000	195	*	5650
3	Roller	0.0005-0.0015 in.	oil mist	under-race	180-200	330	355	-	830	*	5650
4	Roller	0.0005-0.0015 in.	oil mist	under-race	180-200	320	333	-	645	*	6500

*Data not presently available

TABLE VII. P100 MAIN SHAFT BEARING GENERAL CHARACTERISTICS AT SEA LEVEL TAKEOFF FOR LARGE ENGINE NO. 4

Bearing Location	Bearing Type	Nominal Operating Clearance or Contact Angle	Method of Lubrication	Method of Cooling	Oil-in Temperature (°F)	Bearing Race Temperatures (°F)		Thrust Load (lbf)	Radia Loads (lbf)		X Maximum Maneuver Loads (lbf)
						Inner	Outer		Static (1 g)	Rotor Response Loads	
1	Roller	*	mist	under-race	250	272	279	-	149.7	*	5842
2	Ball	*	oil holes in split inner race	under-race	250	259	275	2940	121.3	*	5842
3	Roller	0.0015 in.	mist	under-race	250	269	276	-	102.0	*	5691
4	Ball	*	oil holes in split inner race	under-race	250	264	290	7460	100.9	*	2401
4-1/2	Roller	*	flood	flood	250	256	258	-	40.0	*	3840
5	Roller	0.0021 in.	mist	under-race	250	275	283	-	227.6	*	3290
6	Roller	0.0020 in.	mist	under-race	250	262	266	-	133.5	*	3840

*Data not presently available
X 3-1/2 rad/sec load

TABLE VIII. MAIN SHAFT BEARING GENERAL CHARACTERISTICS AT SEA LEVEL TAKEOFF FOR LARGE ENGINE NO. 5

Bearing Location	Bearing Type	Nominal Operating Clearance or Contact Angle	Method of Lubrication	Method of Cooling	Oil-in Temperature (°F)	Bearing Race Temperatures (°F)		Thrust Load (lbf)	Radial Loads (lbf)		X Maximum Maneuver Loads (lbf)
						Inner	Outer		Static (1 g)	Rotor Response Loads	
1	Ball	*	oil holes in split inner race	under-race	250	284	350	1,577	298.2	*	12,556
2	Ball	*	oil holes in split inner race	under-race	250	286	350	11,829	176.8	*	14,221
3	Roller	*	jet	under-race	250	365	400	-	86.2	*	36,171
4	Roller	*	jet	under-race	250	365	400	-	303.2	*	50,393
5	Roller	*	flooded by twin jet	under-race	250	287	300	-	143.4	*	12,556

*Data not presently available
X 1 rad/sec

TABLE IX. MAIN SHAFT BEARING GENERAL CHARACTERISTICS AT SEA LEVEL TAKEOFF FOR LARGE ENGINE NO. 6

Bearing Location	Nominal Operating Clearance or Contact Angle	Method of Lubrication	Method of Cooling	Oil-in Temperature (°F)	Bearing Race Temperatures (°F)		Thrust Load (lb_f)	Radial Loads (lb_f)		ⓧ Maximum Maneuver Loads (lb_f)	** Fatigue Life (hr)
					Inner	Outer		(1 g)	Rotor Response Loads		
1	0.0018 in.	four corner relief oil holes (also mist)	under-race	200	248	263	-	41	385	6700	51,000
2	31 deg	oil holes in split inner race	under-race	200	238	348	3500	120	700	6000	3240
3	22.4 deg	oil holes in split inner race	under-race	200	251	296	6000	140	500	5300	1300
4	0.003 in.	four corner relief oil holes (also mist)	under-race	200	304	328	-	230	800	5700	1544
5	0.002 in.	two corner relief oil holes (also mist)	under-outer-race oil slots	200	230	230	-	100	424	1100	16,285

** Based on rotor response loads with life factor
ⓧ 3-1/2 rad/sec load

Bearings at locations 1, 4, & 5 are roller bearings; bearings at locations 2 & 3 are ball bearings.

TABLE X. MAIN SHAFT SEALS - GENERAL CHARACTERISTICS AT SEA LEVEL TAKEOFF FOR SMALL ENGINE NO. 1

Seal Location and Type	Pressure Gradient (psi)	Pressure Gradient Range (psi)	Seal Air Temperature (°F)	Method of Lubrication	Method of Cooling
No. 1 Compartment, Forward Dry Face Seal	0	0	90	Oil Mist	Oil Cooled Seal Plate
No. 1 Compartment, Aft Dry Face Seal	4	4	490	Oil Mist	Oil Cooled Seal Plate
No. 2 Compartment, Forward Dry Face Seal	39	39	742	Oil Mist	Oil Cooled Seal Plate
No. 2 Compartment, Aft Dry Face Seal	15	15	742	Oil Mist	Oil Cooled Seal Plate

TABLE XI. MAIN SHAFT SEALS - GENERAL CHARACTERISTICS AT SEA LEVEL TAKEOFF FOR SMALL ENGINE NO. 2

Seal Location and Type	Pressure Gradient (psi)	Pressure Gradient Range (psi)	Seal Air Temperature (°F)	Method of Lubrication	Method of Cooling
No. 1 Ring Seal	21	21	600	Oil Mist	Oil Mist
No. 2 Dry Face Seal	25	25	600	Oil Mist	Oil Cooled Seal Plate
No. 3 Dry Face Seal	53	53	590	Oil Mist	Oil Cooled Seal Plate

TABLE XII. MAIN SHAFT SEALS - GENERAL CHARACTERISTICS AT SEA LEVEL TAKEOFF FOR LARGE ENGINE NO. 1

Seal Location and Type	Method of Cooling	Method of Lubrication	SLTO Pressure Gradient (psi)	Pressure Gradient Range (psi)	SLTO Air Temperature (° F)
No. 1 Dry Face Seal	Oil Mist	Oil Mist	2	4	440
No. 2 Dry Face Seal	Oil Mist	Oil Mist	37	39	440
No. 3 Dry Face Seal	Oil Cooled Seal Plate	Oil Mist	52	55	700
No. 4 Dry Face Seal	Oil Mist	Oil Mist	99	99	840
No. 4 1/2 Triple Carbon Riding Ring Seal	Oil Flow Under Seal Plate	Oil Mist	94	94	840
No. 5 Dry Face Seal	Oil Jet Cooled Seal Plate	Oil Mist	94	94	840
No. 6 Ring Seal	Oil Mist	Oil Mist	12	14	550
No. 6 Back-to-Back Ring Seal	Oil Mist	Oil Mist	12	14	550

TABLE XIII. MAIN SHAFT SEALS - GENERAL CHARACTERISTICS AT SEA LEVEL TAKEOFF FOR LARGE ENGINE NO. 2

Seal Location and Type	Method of Cooling	Method of Lubrication	SLTO Pressure Gradient (psi)	Pressure Gradient Range (psi)	SLTO Air Temperature (° F)
No. 4-1/2 Three-Stage Carbon Riding Ring Seal	Oil on Inside Diameter	Oil Mist	73	81	870
No. 5 Dry Face Seal	Oil Cooled Seal Plate	Oil Mist	73	81	870
No. 6 Ring Seal	Oil on Inside Diameter	Oil Mist	13	15	500
No. 6 Back-to-Back Ring Seal	Oil on Inside Diameter	Oil Mist	13	15	500

TABLE XIV. MAIN SHAFT SEALS - GENERAL CHARACTERISTICS AT SEA LEVEL TAKEOFF FOR LARGE ENGINE NO. 3

Seal Location and Type	Method of Cooling	Method of Lubrication	SLTO Pressure Gradient (psi)	Pressure Gradient Range (psi)	SLTO Air Temperature (°F)
No. 1 Dry Face Seal	Oil Mist	Oil Mist	29	29	468
No. 1-1/2 Front and Rear Dry Face Seals	Oil Cooled Seal Plates	Oil Mist	50	50.3	727
No. 4 Ring Seal Back-to-Back	Oil Mist	Oil Mist	19	19	480

TABLE XV. MAIN SHAFT SEALS - GENERAL CHARACTERISTICS AT SEA LEVEL TAKEOFF FOR LARGE ENGINE NO. 4

Seal Location and Type	Method of Cooling	Method of Lubrication	SLTO Pressure Gradient (psi)	Pressure Gradient Range (psi)	SLTO Air Temperature (°F)
No. 1 Dry Face	Oil Cooled Seal Plate	Oil Mist	25	39	435
No. 2 Dry Face	Oil Cooled Seal Plate	Oil Mist	64	96	596
No. 3 Dry Face	Oil Cooled Seal Plate	Oil Mist	63	89	678
No. 4 Wet Face	Oil Cooled Seal Plate	Oil Holes at Rubbing Face	58	84	913
No. 4-1/2 Triple Carbon Riding Ring Seal	Oil Cooled Seal Plate	Oil Mist	41	61	546
No. 5 Wet Face	Oil Cooled Seal Plate	Oil Holes at Rubbing Face	62	90	546
No. 6 Back-to-Back Ring Seal	Oil Cooled Seal Plate	Oil Mist	13	29	781

TABLE XVI. MAIN SHAFT SEALS - GENERAL CHARACTERISTICS AT SEA LEVEL TAKEOFF FOR LARGE ENGINE NO. 5

Seal Location and Type	Method of Cooling	Method of Lubrication	SLTO Pressure Gradient (psi)	Pressure Gradient Range (psi)	SLTO Air Temperature (° F)
No. 1 Dry Face Seal	Oil Cooled Seal Plate	Oil Mist	49	55	523
No. 1-2 Front and Rear Dry Face Seals	Oil Cooled Seal Plate	Oil Mist	65	80	745
No. 2 Dry Face Seal	Oil Cooled Seal Plate	Oil Mist	49	68	523
No. 3 Wet Face Seal	Oil Cooled Seal Plate	Oil Holes at Seal Rubbing Surface	100	127	1150
No. 4 Wet Face Seal	Oil Cooled Seal Plate	Oil Holes at Seal Rubbing Surface	100	127	1150
No. 5 Back-to-Back Ring Seal	Oil Cooled Seal Plate	Oil Mist	49	68	1047

TABLE XVII. MAIN SHAFT SEALS - GENERAL CHARACTERISTICS AT SEA LEVEL TAKEOFF FOR LARGE ENGINE NO. 6

Seal Location and Type	Method of Cooling	Method of Lubrication	SLTO Pressure Gradient (psi)	Pressure Gradient Range (psi)	SLTO Air Temperature (° F)
No. 1 Dry Face Seal	Oil Cooled Seal Plate	Oil Mist	12.7	29.2	353
No. 2 Front and Rear Dry Face Seals	Oil Cooled Seal Plate	Oil Mist	29.2 (Front) 63.8 (Rear)	58.8 (Front) 108.3 (Rear)	353 (Front) 646 (Rear)
No. 3 Wet Face Seal (Front)	Oil Cooled Seal Plate	Oil Holes at Rubbing Face of Seal	63.8	108.3	646
No. 3 Wet Face Seal (Rear)	Oil Cooled Seal Plate	Oil Holes at Rubbing Face of Seal	53.8	95.7	483
No. 4 Comp. Front and Rear Wet Face Seals	Oil Cooled Seal Plate	Oil Holes at Rubbing Face of Seal	57.2	62.87	646
No. 5 Dry Face Seal	Oil Cooled Seal Plate	Oil Mist	48	*	683

*Data not available

TABLE XVIII. SMALL ENG

Bearing Location and Type	Vendor	ID (in.)	ID (mm)	OD (in.)	Width ID (in.)	Width OD (in.)	Pitch Diameter (in.)	M
No. 1 Roller Bearing	5	1.7802	45.3	2.7559	0.4744	0.4824	2.327	C 3
	4	1.7802	45.3	2.7559	0.4744	0.4824	2.325	P
No. 2 Ball Bearing	4	1.5748	40	2.460	1.084	0.944	2.0174	P
	9	1.5748	40	2.460	1.084	0.957	2.017	P
No. 3 Ball Bearing	3	1.9685	50	4.0855	1.050	0.7894	2.8092	P
	4	1.9685	50	4.0855	1.050	0.7894	2.7460	P
	1	1.9685	50	4.0855	1.050	0.7894	2.7760	P
No. 4 Roller Bearing	1	2.255	57.3	3.7402	0.7330	0.9600	3.0407	P
	5	2.255	57.3	3.7402	0.7330	0.9600	3.001	P
No. 5 Ball Bearing	3	2.3622	60	4.1339	0.8561	0.8631	3.24805	P
	4	2.3622	60	4.1339	0.8561	0.8631	3.2480	P
	9	2.3622	60	4.1339	0.8561	0.8661	3.2480	PV
	3	2.3622	60	4.1339	0.8561	0.8631	3.24805	PV
Upper T/S Ball Bearing	3	0.7874	20	1.4567	0.7874	0.3543	1.122	PV
Lower T/S Ball Bearing	3	0.5906	15	1.380	0.4331	0.530	0.9843	PV

L ENGINE NO. 1 MAIN SHAFT BEARINGS

ter	Ring Material	Element Material	Number of Elements	Element Diameter (in.)	Ball-Race Curvatures Inner (%)	Outer (%)	Total Length (in.)	L/D Ratio	Cage Type
	CEVM 315	CEVM 315	22	0.2283	-	-	0.2800	1.23	One-Piece Machined
	PWA 725	PWA 725	20	0.25	-	-	0.25	1.00	One-Piece Machined
	PWA 725	PWA 725	18	0.25	52	52	-	-	One-Piece Machined
	PWA 725	PWA 725	18	0.2656	53	53	-	-	One-Piece Machined
	PWA 725	PWA 725	15	0.50	52				One-Piece Machined
	PWA 725	PWA 725	14	0.50	52				One-Piece Machined
	PWA 725	PWA 725	13	0.5625	52/ 52.18	58/ 52.35	-	-	One-Piece Machined
	PWA 725	PWA 725	18	0.3543	52/ 52.18	52/ 52.35	0.3465	0.98	One-Piece Machined
	PWA 725	PWA 725	20	0.3389	52/ 52.18	52/ 52.35	0.3465	1.16	One-Piece Machined
5	PWA 725	PWA 725	15	0.531	52/ 52.18	52/ 52.35	-	-	One-Piece Machined
	PWA 725	PWA 725	15	0.531	52/ 52.18	52/ 52.35	-	-	One-Piece Machined
	PWA 725	PWA 725	15	0.531	52/ 52.18	52/ 52.35	-	-	One-Piece Machined
5	PWA 725	PWA 725	15	0.531	52/ 52.18	52/ 52.35	-	-	One-Piece Machined
	PWA 725	PWA 725	10	0.1875	52	52	-	-	One-Piece Machined
	PWA 725	PWA 725	7	0.25	52	52	-	-	Two-Piece, Riveted

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TABLE XIX. SMALL ENGINE NO. 2 MA

Bearing Location and Type	Vendor No.	ID (in.)	ID (mm)	OD (in.)	Width ID (in.)	Width OD (in.)	Pitch Diameter (in.)	Ring Material	Elem Mate
No. 1 Roller Bearing	1	2.9528	75	4.1339	0.810	0.8268	3.563	AMS 6441 or	AMS 6440 6441
	5	2.9528	75	4.1339	0.810	0.8268	3.544	AMS 6294	AMS 6440 6441
No. 2 Ball Bearing	1	3.1496	80	5.1181	1.122	0.9055	4.272	PWA 723	PWA
No. 3 Roller Bearing	1	3.1496	80	4.3307	0.9449	0.6299	3.753	PWA 725	PWA

TABLE XX. SMALL ENGINE NO. 3

Bearing Location and Type	Vendor No.	ID (in.)	ID (mm)	OD (in.)	Width ID (in.)	Width OD (in.)	Pitch Diameter (in.)	Ring Material	Elem Mate
No. 1 Ball Bearing	1	1.1811	30	2.8346	0.9055	0.748	2.047	PWA 723	PWA
Nos. 2, 3 Roller Bearing	1	1.5748	40	2.6672	0.5907	0.5906	2.126	PWA 725	PWA
No. 4 Ball Bearing	1	1.1811	30	2.8346	0.9055	0.748	2.047	PWA 723	PWA

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NE NO. 2 MAIN SHAFT BEARINGS

ing terial	Element Material	Number of Elements	Element Diameter (in.)	Ball-Race Curvatures Inner (%)	Outer (%)	Total Length (in.)	L/D Ratio	Cage Type
S 1 or	AMS 6440 or 6441	28	0.3150	-	-	0.4331	1.375	One-Piece Machined
S 4	AMS 6440 or 6441	26	0.3145	-	-	0.3537	1.125	One-Piece Machined
A 723	PWA 723	20	0.59375	51.75/52	51.75/52	-	-	One-Piece Machined
A 725	PWA 725	30	0.3150			0.4252	1.35	One-Piece Machined

NGINE NO. 3 MAIN SHAFT BEARINGS

ing terial	Element Material	Number of Elements	Element Diameter (in.)	Ball-Race Curvatures Inner (%)	Outer (%)	Total Length (in.)	L/D Ratio	Cage Type
A 723	PWA 723	10	0.53125	52	52	-	-	One-Piece (Rabbit Ear Style of Ball Retention)
A 725	PWA 725	16	0.2953	-	-	0.3465	1.175	One-Piece Machined
A 723	PWA 723	10	0.53125	52	52	-	-	One-Piece (Rabbit Ear Style of Ball Retention)

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TABLE XXI. LARGE ENGINE NO. 1 MAIN SHAFT BE

Bearing Location and Type	Vendor	ID (in.)	ID (mm)	OD (in.)	Width ID (in.)	Width OD (in.)	Pitch Diameter (in.)	Ring Material	Element Material	Number of Elements	Dian (i
No. 1 Roller Bearing	1	5.1181	130	7.0866	1.0236	0.8661	6.142	PWA 723	PWA 723	26	0.55
	5	5.1181	130	7.0866	1.0236	0.8661	6.1035	PWA 742	PWA 742	30	0.49
No. 2 Ball Bearing	2	5.1181	130	7.874	2.560	2.560	6.496	PWA 725	PWA 725	21	0.81
	3	5.1181	130	7.874	2.560	2.560	6.496	PWA 725	PWA 725	21	0.81
	4	5.1181	130	7.874	2.560	2.560	6.4734	PWA 725	PWA 725	21	0.81
	1	5.1181	130	7.874	2.560	2.560	6.496	PWA 725	PWA 725	21	0.81
No. 2-1/2 Ball Bearing	3	4.3307	110	5.9055	1.00	0.7874	5.11815	PWA 723	PWA 723	19	0.46
	2	4.3307	110	5.9055	1.00	0.7874	5.1180	PWA 723	PWA 723	19	0.5
No. 3 Roller Bearing	5	4.2520	108	5.6693	0.7874	0.9449	4.953	PWA 742	PWA 742	30	0.36
	1	4.2520	108	5.6693	0.7874	0.9449	4.961	PWA 725	PWA 725	34	0.35
	2	4.2520	108	5.6693	0.7874	0.9449	4.9528	PWA 725	PWA 725	32	0.36
No. 4 Ball Bearing	4	5.5118	140	8.6614	3.1496	3.1496	7.0610	PWA 723	PWA 723	20	0.937
	3	5.5118	140	8.6614	3.1496	3.1496	7.0866	PWA 723	PWA 723	20	0.937
	2	5.5118	140	8.6614	3.1496	3.1496	7.087	PWA 723	PWA 723	20	0.937
	1	5.5118	140	9.6614	3.1496	3.1496	7.087	PWA 723	PWA 723	19	1.000
No. 4-1/2 Ball Bearing	1	3.9500	101	5.200	0.6299	1.2598	4.575	PWA 725	PWA 725	36	0.315
	5	3.9500	101	5.200	0.6299	1.2598	4.5742	PWA 724	PWA 724	34	0.314
No. 5 Roller Bearing	1	5.9051	150	8.4646	1.3780	1.0236	7.17	PWA 725	PWA 725	28	0.669
	5	5.9051	150	8.4646	1.3780	1.0236	7.2783	PWA 725	PWA 725	28	0.669
No. 6 Roller Bearing	5	2.7559	70	4.3307	0.8661	1.1811	3.5445	AMS 6294	AMS 6440	24	0.363
	2	2.7559	70	4.3307	0.8661	1.1811	3.5493	AMS 6440	AMS 6274	24	0.363
	4	2.7559	70	4.3307	0.8661	1.1811	3.5433	AMS 6440	AMS 6440	24	0.393

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E XXI. LARGE ENGINE NO. 1 MAIN SHAFT BEARINGS

Pitch Diameter (in.)	Ring Material	Element Material	Number of Elements	Diameter (in.)	Ball-Race Curvature Inner	Ball-Race Curvature Outer	Total Length (in.)	L/D Ratio	Cage Type
6.142	PWA 723	PWA 723	26	0.5512	-	-	0.5512	1.00	One-Piece Machined
6.1035	PWA 742	PWA 742	30	0.4985	-	-	0.5337	1.07	One-Piece Machined
6.496	PWA 725	PWA 725	21	0.8125	0.52	0.516	-	-	One-Piece
6.496	PWA 725	PWA 725	21	0.8125	0.514	0.514	-	-	One-Piece
6.4734	PWA 725	PWA 725	21	0.8125	0.515	0.515	-	-	One-Piece
6.496	PWA 725	PWA 725	21	0.8125	0.515/ 0.5175	0.515/ 0.5175	-	-	One-Piece
5.11815	PWA 723	PWA 723	19	0.4688	0.515	0.515	-	-	Two-Piece, Riveted
5.1180	PWA 723	PWA 723	19	0.5	0.516	0.53	-	-	Two-Piece, Riveted
4.953	PWA 742	PWA 742	30	0.3629	-	-	0.3937	1.08	One-Piece Machined
4.961	PWA 725	PWA 725	34	0.3543	-	-	0.3465	0.98	One-Piece Machined
4.9528	PWA 725	PWA 725	32	0.3637	-	-	0.3543	0.975	One-Piece Machined
7.0610	PWA 723	PWA 723	20	0.9375	0.52	0.52	-	-	One-Piece Machined
7.0866	PWA 723	PWA 723	20	0.9375	0.521	0.521	-	-	One-Piece Machined
7.087	PWA 723	PWA 723	20	0.9375	0.52	0.52	-	-	One-Piece Machined
7.087	PWA 723	PWA 723	19	1.000	0.515/ 0.5175	0.52/ 0.5225	-	-	One-Piece Machined
4.575	PWA 725	PWA 725	36	0.3150	-	-	0.3071	0.975	One-Piece Machined
4.5742	PWA 724	PWA 724	34	0.3145	-	-	0.3902	1.24	One-Piece Machined
7.17	PWA 725	PWA 725	28	0.6693	-	-	0.6614	0.99	One-Piece Machined
7.2783	PWA 725	PWA 725	28	0.6693	-	-	0.6693	1.00	One-Piece Machined
3.5445	AMS 6294	AMS 6440	24	0.3633	-	-	0.4587	1.26	One-Piece Machined
3.5493	AMS 6440	AMS 6274	24	0.3637	-	-	0.4587	1.26	One-Piece Machined
3.5433	AMS 6440	AMS 6440	24	0.3937	-	-	0.4587	1.00	One-Piece Machined

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TABLE XXII. LARGE ENGINE NO. 2 MAI

Bearing Location and Type	Vendor No.	ID (in.)	ID (mm)	OD (in.)	Width ID (in.)	Width OD (in.)	Pitch Diameter (in.)	Ring Material	Element Material	Nu o Ele
No. 1 Roller Bearing	1	3.7402	95	5.550	1.0074	2.061	4.488	AMS 6440	AMS 6440	2
	5	3.7402	95	5.550	1.0074	2.061	4.551	AMS 6294	AMS 6440	2
No. 2 Ball Bearing	1	3.937	100	6.49605	2.560	2.560	5.295	PWA 725	PWA 725	1
	3	3.937	100	6.49605	2.560	2.560	5.21655	PWA 725	PWA 725	18
	4	3.937	100	6.49605	2.560	2.560	5.2165	PWA 725	PWA 725	1
No. 3 Ball Bearing	4	4.508	115	6.8897	1.1024	1.0908	5.6727	PWA 725	PWA 725	1
	3	4.508	115	6.8897	1.1024	1.0908	5.7087	PWA 725	PWA 725	15
No. 4 Ball Bearing	1	4.9213	125	7.4803	2.560	2.560	6.280	PWA 725	PWA 725	21
	3	4.9213	125	7.4803	2.560	2.560	6.2008	PWA 725	PWA 725	21
	4	4.9213	125	7.4803	2.560	2.560	6.2008	PWA 725	PWA 725	21
No. 4-1/2 Roller Bearing	5	3.1496	80	4.2516	0.6300	0.8650	3.6412	PWA 742	PWA 742	32
No. 5 Roller Bearing	5	5.1181	130	7.0893	1.4961	0.9843	6.102	PWA 742	PWA 742	28
No. 6 Roller Bearing	5	3.3465	85	5.041	0.8755	1.5	4.1355	PWA 742	PWA 742	28
	1	3.3465	85	5.041	0.8755	1.5	4.134	PWA 725	PWA 725	26

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XXII. LARGE ENGINE NO. 2 MAIN SHAFT BEARINGS

tch meter in.)	Ring Material	Element Material	Number of Elements	Element Diameter (in.)	Ball-Race Curvatures Inner	Outer	Total Length (in.)	L/D Ratio	Cage Type
88	AMS 6440	AMS 6440	26	0.4331	-	-	0.5118	1.18	One-Piece Machined
51	AMS 6294	AMS 6440	28	0.3827	-	-	0.4587	1.2	One-Piece Machined
95	PWA 725	PWA 725	18	0.8125	0.5175/ 0.52	0.5175/ 0.52	-	-	One-Piece Machined
1655	PWA 725	PWA 725	18	0.8125	0.52	0.515	-	-	One-Piece Machined
165	PWA 725	PWA 725	18	0.8125	0.52	0.52	-	-	One-Piece Machined
727	PWA 725	PWA 725	16	0.6250	0.51	0.52	-	-	Two-Piece, Riveted
087	PWA 725	PWA 725	15	0.6250	0.52	0.52	-	-	Two-Piece, Riveted
80	PWA 725	PWA 725	21	0.8125	0.515/ 0.5175	0.52/ 0.5225	-	-	One-Piece Machined
008	PWA 725	PWA 725	21	0.8125	0.52	0.515	-	-	One-Piece Machined
008	PWA 725	PWA 725	21	0.8125	0.52	0.52	-	-	One-Piece Machined
412	PWA 742	PWA 742	32	0.2490	-	-	0.3537	1.42	One-Piece Machined
02	PWA 742	PWA 742	28	0.4980	-	-	0.5737	1.15	One-Piece Machined
355	PWA 742	PWA 742	28	0.3643	-	-	0.4587	1.26	One-Piece Machined
34	PWA 725	PWA 725	26	0.3937	-	-	0.3858	0.98	One-Piece Machined

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TABLE XXIII. LARGE ENGINE NO. 3 MAIN S

Bearing Location and Type	Vendor No.	ID (in.)	ID (mm)	OD (in.)	Width ID (in.)	Width OD (in.)	Pitch Diameter (in.)	Ring Material	Element Material	N El
No. 1 Ball Bearing	3	8.2648	210	13.7795	2.4409	2.2047	11.200	PWA 725	PWA 725	
No. 2 Ball Bearing	4	8.6614	220	12.6	1.8065	1.811	10.6299	PWA 725	PWA 725	
	3	8.6614	220	12.6	1.8065	1.811	10.6299	PWA 725	PWA 725	
No. 3 Roller Bearing	1	9.2520	235	12.2047	1.620	1.820	10.72	PWA 725	PWA 725	
	1	9.2520	235	12.2047	1.620	1.820	10.72	PWA 725	PWA 725	
No. 4 Roller Bearing	4	6.4961	165	9.0551	1.6142	1.1811	7.7800	PWA 723	PWA 723	
	4	6.4961	165	9.0551	1.6142	1.1811	7.78	PWA 725	PWA 725	
	2	6.4961	165	9.0551	1.6142	1.1811	7.7627	PWA 725	PWA 725	

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II. LARGE ENGINE NO. 3 MAIN SHAFT BEARINGS

Pitch Diameter (in.)	Ring Material	Element Material	Number of Elements	Element Diameter (in.)	Base-Line Curvatures Inner	Base-Line Curvatures Outer	Total Length (in.)	L/D Ratio	Cage Type
11.200	PWA 725	PWA 725	20	1.5625	0.525	0.525	-	-	One-Piece Machined
10.6299	PWA 725	PWA 725	25	1.125	0.52	0.52	-	-	One-Piece Machined
10.6299	PWA 725	PWA 725	25	1.125	0.5225	0.5225	-	-	One-Piece Machined
10.72	PWA 725	PWA 725	32	0.9055	-	-	0.8976	0.99	One-Piece Machined
10.72	PWA 725	PWA 725	32	0.9055	-	-	0.8976	0.99	One-Piece Machined
7.7800	PWA 723	PWA 723	28	0.7087	-	-	0.7087	1.00	One-Piece Machined
7.78	PWA 725	PWA 725	28	0.7087	-	-	0.7087	1.00	One-Piece Machined
7.7627	PWA 725	PWA 725	26	0.7411	-	-	0.7600	1.02	One-Piece Machined

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TABLE XXIV. LARGE ENGINE NO. 4 M

Bearing Location and Type	Vendor No.	ID (in.)	ID (mm)	OD (in.)	Width ID (in.)	Width OD (in.)	Pitch Diameter (in.)	Ring Material	Element Material
No. 1 Roller Bearing	1	3.7402	95	5.4336	1.0074	1.2300	4.528	PWA 725	PWA 725
	2	3.7402		5.4336	1.0074	1.2300	4.528	PWA 725	PWA 725
No. 2 Ball Bearing	4	4.33070	110	6.2992	0.9449	0.947	5.314	PWA 725	PWA 725
	3	4.33070		6.2992	0.9449	0.947	5.2999	PWA 725	PWA 725
No. 3 Roller Bearing	1	3.9360	100	5.5118	0.6625	0.760	4.723	PWA 725	PWA 725
	2	3.9360	100	5.5118	0.6625	0.760	4.723	PWA 725	PWA 725
	4	3.9360	100	5.5118	0.6625	0.760	4.723	PWA 725	PWA 725
No. 4 Ball Bearing	3	4.4488	113	7.087	1.281	1.1811	5.6904	PWA 725	PWA 725
	2	4.4488	113	7.087	1.281	1.1811	5.787	PWA 725	PWA 725
	1	4.4488	113	7.087	1.281	1.1811	5.827	PWA 725	PWA 725
No. 4-1/2 Roller Bearing	4	3.1050	79	4.3116	0.7874	1.0236	3.701	PWA 725	PWA 725
	1	3.1050	79	4.3116	0.7874	1.0236	3.701	PWA 725	PWA 725
	5	3.1050	79	4.3116	0.7874	1.0236	3.701	PWA 725	PWA 725
No. 5 Roller Bearing	1	4.8939	124.5	6.7461	1.063	0.9449	5.820	PWA 725	PWA 725
	5	4.8939	124.5	6.7461	1.063	0.9449	5.9339	PWA 725	PWA 725
	4	4.8939	124.5	6.7461	1.063	0.9449	5.950	PWA 725	PWA 725
No. 6 Roller Bearing	2	2.5591	65	4.2523	0.9487	1.4176	3.372	PWA 725	PWA 725
	4	2.5591	65	4.2523	0.9487	1.4176	3.353	PWA 725	PWA 725
	5	2.5591	65	4.2543	0.9487	1.4176	3.382	PWA 725	PWA 725

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LE XXIV. LARGE ENGINE NO. 4 MAIN SHAFT BEARINGS

Pitch Diameter (in.)	Ring Material	Element Material	Number of Elements	Element Diameter (in.)	Ball-Race Curvatures Inner	Ball-Race Curvatures Outer	Total Length (in.)	L/D Ratio	Cage Type
4.528	PWA 725	PWA 725	26	0.3337	-	-	0.3858	1.16	One-Piece Machined
4.528	PWA 725	PWA 725	24	0.3871	-	-	0.420	1.09	One-Piece Machined
5.314	PWA 725	PWA 725	22	0.625	0.52	0.52	-	-	One-Piece Machined
5.2999	PWA 725	PWA 725	22	0.625	0.52	0.515	-	-	One-Piece Machined
4.723	PWA 725	PWA 725	30	0.3543	-	-	0.3465	0.98	One-Piece Machined
4.723	PWA 725	PWA 725	32	0.3350	-	-	0.360	1.07	One-Piece Machined
4.723	PWA 725	PWA 725	30	0.3543	-	-	0.3543	1.00	One-Piece Machined
5.6904	PWA 725	PWA 725	20	0.750	0.52	0.52	-	-	One-Piece Machined
5.787	PWA 725	PWA 725	20	0.750	0.53	0.52	-	-	One-Piece Machined
5.827	PWA 725	PWA 725	20	0.750	0.5187/ 0.5213	0.5187/ 0.5213	-	-	One-Piece Machined
3.701	PWA 725	PWA 725	32	0.2756	-	-	0.3307	1.20	One-Piece Machined
3.701	PWA 725	PWA 725	32	0.2953	-	-	0.3465	1.17	One-Piece Machined
3.701	PWA 725	PWA 725	30	0.2799			0.3537	1.26	One-Piece Machined
5.820	PWA 725	PWA 725	30	0.4724	-	-	0.4646	0.98	One-Piece Machined
5.9339	PWA 725	PWA 725	30	0.4980	-	-	0.5737	1.15	One-Piece Machined
5.950	PWA 725	PWA 725	30	0.4724	-	-	0.4724	1.00	One-Piece Machined
3.372	PWA 725	PWA 725	20	0.3148	-	-	0.350	1.11	One-Piece Machined
3.353	PWA 725	PWA 725	24	0.3150	-	-	0.3150	1.00	One-Piece Machined
3.382	PWA 725	PWA 725	24	0.3543	-	-	0.3543	1.00	One-Piece Machined

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TABLE XXV. LARGE ENGINE NO. 5 MA

Bearing Location and Type	Vendor No.	ID (in.)	ID (mm)	OD (in.)	Width ID (in.)	Width OD (in.)	Pitch Diameter (in.)	Ring Material	Element Material
No. 1 Ball Bearing	3	4.9213	125	7.4803	1.280	1.280	6.0008	PWA 725	PWA 725
No. 2 Ball Bearing	6	5.7087	145	8.2677	1.280	1.280	6.8900	PWA 725	PWA 725
No. 3 Roller Bearing	6	6.8898	175	9.0551	1.250	1.420	8.015	PWA 725	PWA 725
No. 4 Roller Bearing	6	6.6929	170	9.0551	1.300	1.440	8.00	PWA 725	PWA 725
No. 5 Roller Bearing (1)	5	2.5591	65	3.937	0.700	1.100	3.25	PWA 725	PWA 725
	7,8	2.5591	65	3.937	0.700	1.100	3.25	PWA 725	PWA 725

(1) Outer Race Rotation

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RGE ENGINE NO. 5 MAIN SHAFT BEARINGS

Ring Material	Element Material	Number of Elements	Element Diameter (in.)	Ball-Race Curvatures Inner	Outer	Total Length (in.)	L/D Ratio	Cage Type
PWA 725	PWA 725	20	0.8125	0.515	0.52			One-Piece Machined
PWA 725	PWA 725	23	0.8125	0.515	0.515			One-Piece Machined
WA 725	PWA 725	32	0.6323	-	-	0.7237	1.14	One-Piece Machined
WA 725	PWA 725	32	0.5910	-	-	0.6610	1.12	One-Piece Machined
WA 725	PWA 725	22	0.3634	-	-	0.4587	1.26	One-Piece Machined
WA 725	PWA 725	20	0.354	-	-	0.354	1.00	One-Piece Machined

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TABLE XXVI. LARGE ENGINE NO. 6 MAIN SHAFT BEARINGS

Bearing Location and Type	Vendor No.	ID (in.)	ID (mm)	OD (in.)	Width ID (in.)	Width OD (in.)	Pitch Diamter (in.)	Ring Material	Element Material	Number of Elements	Element Diameter (in.)
No. 1 Roller Bearing	5	3.9370	100	5.8781	1.1417	1.500	4.76	PWA 725	PWA 725	20	0.5512
	4	3.970	100	5.8781	1.1417	1.500	4.76	PWA 725	PWA 725	-	-
	7	3.970	100	5.8781	1.1417	1.500	4.76	PWA 725	PWA 725	-	-
No. 2 Ball Bearing	3	4.3307	110	6.6929	1.408	1.1417	5.5118	PWA 725	PWA 725	18	0.750
	4	4.3307	110	6.6929	1.408	1.1417	5.5118	PWA 725	PWA 725	18	0.750
	2	4.3307	110	6.6929	1.408	1.1417	5.5118	PWA 725	PWA 725	18	0.750
	9	4.3307	110	6.6929	1.408	1.1417	5.5118	PWA 725	PWA 725	18	0.750
No. 3 Ball Bearing	3	6.1024	155	8.8583	1.686	1.4173	7.4804	PWA 725	PWA 725	20	0.90625
	4	6.1024	155	8.8583	1.686	1.4173	7.4804	PWA 725	PWA 725	20	0.90625
	2	6.1024	155	8.8583	1.686	1.4173	7.4804	PWA 725	PWA 725	20	0.90625
No. 4 Roller Bearing	4	6.4961	165	8.8583	1.2583	1.3780	7.75	PWA 725	PWA 725	32	0.6299
	5	6.4961	165	8.8583	1.2583	1.3780	7.75	PWA 725	PWA 725	32	0.6299
No. 5 Roller Bearing	4	3.1496	80	4.9213	2.0079	1.6535	4.055	PWA 725	PWA 725	22	0.4331
	2	3.1496	80	4.9213	2.0079	1.6535	4.055	PWA 725	PWA 725	22	0.4331
	7	3.1496	80	4.9213	2.0079	1.6535	4.055	PWA 725	PWA 725	22	0.4331

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XXVI. LARGE ENGINE NO. 6 MAIN SHAFT BEARINGS

Pitch Diamter (in.)	Ring Material	Element Material	Number of Elements	Element Diameter (in.)	Ball-Race Curvatures Inner (%)	Ball-Race Curvatures Outer (%)	Total Length (in.)	L/D Ratio	Cage Type
4.76	PWA 725	PWA 725	20	0.5512	-	-	0.5906	1.07	One-Piece Machined
4.76	PWA 725	PWA 725	-	-	-	-	-	-	Rollers Separable from Cage
4.76	PWA 725	PWA 725	-	-	-	-	-	-	
5.5118	PWA 725	PWA 725	18	0.750	52.5	52	-	-	One-Piece Machined
5.5118	PWA 725	PWA 725	18	0.750	52.5	52	-	-	One-Piece Machined
5.5118	PWA 725	PWA 725	18	0.750	52.5	52	-	-	One-Piece Machined
5.5118	PWA 725	PWA 725	18	0.750	52.5	52	-	-	One-Piece Machined
7.4804	PWA 725	PWA 725	20	0.90625	52	52	-	-	One-Piece Machined
7.4804	PWA 725	PWA 725	20	0.90625	52	52	-	-	One-Piece Machined
7.4804	PWA 725	PWA 725	20	0.90625	52	52	-	-	One-Piece Machined
7.75	PWA 725	PWA 725	32	0.6299	-	-	0.6299	1.00	One-Piece Machined
7.75	PWA 725	PWA 725	32	0.6299	-	-	0.6299	1.00	Roller Separable from Cage
4.055	PWA 725	PWA 725	22	0.4331	-	-	0.4331	1.00	One-Piece Machined
4.055	PWA 725	PWA 725	22	0.4331	-	-	0.4331	1.00	Rollers Separable from Cage
4.055	PWA 725	PWA 725	22	0.4331	-	-	0.4331	1.00	Rollers Separable from Cage

TABLE XXVII. SMALL ENGINE NO. 1 MAIN SHAFT SEALS						
Seal Location and Type	Secondary Seal Type	Method Of Spring Loading	Nose Width (in.)	Face Width (in.)	Pitch Diameter (in.)	Pressure Balance Ratio (%)
No. 1 Compartment Forward Dry Face Seal (CDJ-83)	Piston Ring	Wave Washer	0.030/ 0.020	0.150	2.634	55
No. 1 Compartment Aft Dry Face Seal	Piston Ring	Bellows Spring	0.035/ 0.030	0.148	2.555	55
No. 2 Compartment Forward Dry Face Seal	Piston Ring	Bellows Spring	0.035/ 0.030	0.150	2.929	81
No. 2 Compartment Aft Dry Face Seal	Piston Ring	Bellows	0.035/ 0.030	0.150	3.414	55

TABLE XXVIII. SMALL ENGINE NO. 2 MAIN SHAFT SEALS						
Seal Location and Type	Secondary Seal Type	Method Of Spring Loading	Nose Width (in.)	Face Width (in.)	Pitch Diameter (in.)	Pressure Balance Ratio (%)
No. 1 Ring Seal	None	None	0.040	0.037	3.811	-
No. 2 Dry Face Seal	Piston Ring	Springs	0.080	0.150	3.702	67
No. 3 Dry Face Seal	Piston Ring	Springs	0.060	0.150	3.702	67

TABLE XXIX. LARGE ENGINE NO. 1 MAIN SHAFT SEALS

Seal Location and Type	Secondary Seal Type	Method Of Spring Loading	Nose Width (in.)	Face Width (in.)	Pitch Diameter (in.)	Pressure Balance Ratio (%)
No. 1 Dry Face Seal	Piston Ring	Springs	0.095/ 0.085	0.150	6.31	63.3
No. 2 Dry Face Seal	Piston Ring	Springs	0.095/ 0.085	0.150	6.36	63.3
No. 3 Dry Face Seal	Piston Ring	Springs	0.075/ 0.065	0.150	6.96	63.3
No. 4 Dry Face Seal	Piston Ring	Springs	0.090/ 0.080	0.150	6.76	63.3
No. 4 1/2 Triple Carbon Riding Ring Seal	None	Wave Washer	-	-	-	-
No. 5 Dry Face Seal	Piston Ring	Springs	0.085/ 0.075	0.156	7.018	63.3
No. 6 Ring Seal	None	None	-	-	-	-
No. 6 Back-to-Back Ring Seal	None	Wave Washer	-	-	-	-

TABLE XXX. LARGE ENGINE NO. 2 MAIN SHAFT SEALS

Seal Location and Type	Secondary Seal Type	Method Of Spring Loading	Nose Width (in.)	Face Width (in.)	Pitch Diameter (in.)	Pressure Balance Ratio (%)
No. 4 1/2 Three Stage Carbon Riding Ring Seal	None	Wave Washer	-	-	-	-
No. 5 Dry Face Seal	Piston Ring	Springs	0.085/ 0.075	0.200	6.127	66
No. 6 Ring Seals	None	None	-	-	-	-
No. 6 Back-to-Back Ring Seal	None	Wave Washer	-	-	-	-

TABLE XXXI. LARGE ENGINE NO. 3 MAIN SHAFT SEALS

Seal Location and Type	Secondary Seal Type	Method Of Spring Loading	Nose Width (in.)	Face Width (in.)	Pitch Diameter (in.)	Pressure Balance Ratio (%)
No. 1 Dry Face Seal	Piston Seal Ring	Springs	0.105 0.095	0.150	10.215	64.7
No. 1 1/2 Front and Rear Dry Face Seal	Piston Seal Ring	Springs	0.105/ 0.095	0.150	9.815	65
No. 4 Ring Seal Back-to-Back	None	Wave Washer	-	-	-	-

TABLE XXXII. LARGE ENGINE NO. 4 MAIN SHAFT SEALS

Seal Location and Type	Secondary Seal Type	Method Of Spring Loading	Nose Width (in.)	Face Width (in.)	Pitch Diameter (in.)	Pressure Balance Ratio (%)
No. 1 Dry Face	Piston Ring	Springs	0.120/ 0.100	0.200	4.576	66
No. 2 Dry Face	Piston Ring	Springs	0.130/ 0.110	0.150	5.4977	66
No. 3 Dry Face	Piston Ring	Springs	0.130/ 0.110	0.150	4.868	66
No. 4 Wet Face	Piston Ring	Springs	0.085/ 0.065	0.200	5.300	68
No. 4 1/2 Triple Carbon Riding Ring Seal	Ring Seal	Wave Washer	-	-	-	-
No. 5 Wet Face	Piston Ring	Springs	0.070/ 0.050	0.200	6.200	67.5
No. 6 Back-to-Back Ring Seal	-	Wave Washer	-	-	-	-

TABLE XXXIII. LARGE ENGINE NO. 5 MAIN SHAFT SEALS						
Seal Location and Type	Secondary Seal Type	Method Of Spring Loading	Nose Width (in.)	Face Width (in.)	Pitch Diameter (in.)	Pressure Balance Ratio (%)
No. 1 Dry Face Seal	Piston Seal Ring	Springs	0.080/ 0.070	0.150	6.753	65
No. 1-2 Front and Rear Dry Face Seal	Piston Seal Ring	Springs	0.080/ 0.070	0.150	6.25	66.8
No. 2 Dry Face Seal	Piston Seal Ring	Springs	0.080/ 0.070	0.150	6.753	65.2
No. 3 Wet Face Seal	Piston Seal Ring	Springs	0.120/ 0.100	0.200	8.16	67.5
No. 4 Wet Face Seal	Piston Seal Ring	Springs	0.120/ 0.100	0.200	8.16	67.5
No. 5 Back-to-Back Ring Seal	None	Wave Washer	-	-	-	-

TABLE XXXIV. LARGE ENGINE NO. 6 MAIN SHAFT SEALS						
Seal Location and Type	Secondary Seal Type	Method Of Spring Loading	Nose Width (in.)	Face Width (in.)	Pitch Diameter (in.)	Pressure Balance Ratio (%)
No. 1 Dry Face Seal	Piston Ring	Spring	0.210/ 0.190	0.200	5.382	67
No. 2 Front and Rear Dry Face Seals	Piston Ring	Springs	0.130/ 0.120	0.200	5.12	65
No. 3 Wet Face Seal (Front)	Piston Ring	Springs	0.130/ 0.120	0.200	5.12	65
No. 3 Wet Face Seal (Rear)	Piston Ring	Springs	0.130/ 0.120	0.200	7.08	85
No. 4 Comp. Front and Rear Wet Face Seals	Piston Ring	Springs	0.120/ 0.100	0.225	7.514	70
No. 5 Dry Face Seal	Piston Ring	Springs	0.140/ 0.120	0.200	6.286	67

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TABLE XXXV. SMALL AND LARGE ENGINE PERFORMANC

					Engine	
Engine	SLTO Corrected Airflow Into Engine (pps)	SLTO Corrected Airflow Into High Compressor (pps)	Low Rotor Speed at SLTO (rpm)	High Rotor Speed at SLTO (rpm)	SLTO Engine Thrust With Augmentation (lb_f)	SLTO En Thru Withou Augment (lb_f)
Small Engine 1	8.36	NA*	16,300	36,000	NA	NA
Small Engine 2	52.5	NA	33,000	37,500	NA	3,30
Small Engine 3	6.4	NA	16,000	NA	NA	NA
Large Engine 1	461	55.5	6,560	9,730	NA	18,0
Large Engine 2	315	48	8,800	12,250	NA	14,0
Large Engine 3	1480	127.1	3,742	8,084	NA	43,5
Large Engine 4	255.8	28.7	10,528	14,760	25,100	14,5
Large Engine 5	393	62.8	8,000	12,150	33,400	18,1
Large Engine 6	224	54.9	10,130	13,200	28,131	16,4

*NA - Not applicable or available

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GINE PERFORMANCE AND ROTOR DYNAMIC CHARACTERISTICS

	Engine Parameters					
Engine ust th entation b_f)	SLTO Engine Thrust Without Augmentation (lb_f)	SLTO Engine Thrust to Weight Ratio With Augmentation	SLTO Engine Thrust to Weight Ratio Without Augmentation	SLTO Thrust Specific Fuel Consumption tsfc With Augmentation (lb/hr/lb)	SLTO Thrust Specific Fuel Consumption tsfc Without Augmentation (lb/hr/lb)	Maximum Compressor Blade Tip Speed (f/s)
A	NA	NA	NA	NA	NA	NA
A	3,300	NA	7.06	NA	0.995	1200
A	NA	NA	NA	NA	NA	1735
A	18,000	NA	4.24	NA	0.535	1425
A	14,000	NA	4.52	NA	0.565	1400
A	43,500	NA	5.14	NA	0.365	1430
,100	14,560	6.31	3.66	2.45	0.686	1520
,400	18,100	7.45	4.03	2.06	0.500	1460
,131	16,415	8.22	6.1	2.1	0.642	1450

TABLE XXXVI. CALCULATED BEARING CHARACTERISTICS

MAINSHAFT BEARING CHARACTERISTICS

ROW	COS ALPH	BALL CAP	EFF.LENG	ROLL.CAP	APPR.WT.	DN	ROW TITLE
1	1.000000E 00	0.0	3.300993E-01	1.235564E 04	1.587245E 00	1.207500E 06	SMALL ENG, NO. 2
2	1.000000E 00	0.0	3.106909E-01	9.774361E 03	1.580033E 00	1.207500E 06	SMALL ENG, NO. 2
3	9.063074E-01	1.132738E 04	0.0	0.0	3.453418E 00	1.368500E 06	SMALL ENG, NO. 2
4	1.000000E 00	0.0	3.892000E-01	1.289951E 04	1.369974E 00	1.288000E 06	SMALL ENG, NO. 2
5	1.000000E 00	0.0	2.150000E-01	4.912300E 03	4.838293E-01	7.383898E 05	SMALL ENG, NO. 1
6	9.063074E-01	3.300974E 03	0.0	0.0	7.812736E-01	6.520000E 05	SMALL ENG, NO. 1
7	9.063074E-01	3.058734E 03	0.0	0.0	7.929791E-01	6.520000E 05	SMALL ENG, NO. 1
8	9.205044E-01	6.315117E 03	0.0	0.0	2.340923E 00	1.800000E 06	SMALL ENG, NO. 1
9	9.205044E-01	7.153430E 03	0.0	0.0	2.340923E 00	1.800000E 06	SMALL ENG, NO. 1
10	1.000000E 00	0.0	2.854999E-01	9.213430E 03	1.536624E 00	2.062799E 06	SMALL ENG, NO. 1
11	1.000000E 00	0.0	3.494999E-01	9.393055E 03	1.536840E 00	2.062799E 06	SMALL ENG, NO. 1
12	9.310061E-01	7.594063E 03	0.0	0.0	2.190001E 00	9.828898E 05	SMALL ENG, NO. 1
13	9.310061E-01	7.494063E 03	0.0	0.0	2.190001E 00	9.780000E 05	SMALL ENG, NO. 1
14	9.310061E-01	7.694063E 03	0.0	0.0	2.190001E 00	9.928898E 05	SMALL ENG, NO. 1
15	1.000000E 00	0.0	4.062000E-01	2.612574E 04	4.804089E 00	8.528000E 05	LARGE ENG, NO. 1
16	1.000000E 00	0.0	4.687000E-01	2.447729E 04	4.505871E 00	8.528000E 05	LARGE ENG, NO. 1
17	9.063074E-01	3.280397E 04	0.0	0.0	2.037321E 01	8.528000E 05	LARGE ENG, NO. 1
18	9.063074E-01	3.280397E 04	0.0	0.0	2.037321E 01	8.528000E 05	LARGE ENG, NO. 1
19	9.063074E-01	3.383718E 04	0.0	0.0	2.037321E 01	8.528000E 05	LARGE ENG, NO. 1
20	9.063074E-01	3.280397E 04	0.0	0.0	2.037321E 01	8.528000E 05	LARGE ENG, NO. 1
21	9.063074E-01	6.445832E 03	0.0	0.0	3.061681E 00	7.216000E 05	LARGE ENG, NO. 1
22	9.063074E-01	7.549365E 03	0.0	0.0	3.042839E 00	7.216000E 05	LARGE ENG, NO. 1
23	1.000000E 00	0.0	3.444999E-01	1.351360E 04	2.607940E 00	7.084800E 05	LARGE ENG, NO. 1
24	1.000000E 00	0.0	3.105000E-01	1.297423E 04	2.514895E 00	7.084800E 05	LARGE ENG, NO. 1
25	1.000000E 00	0.0	3.043000E-01	1.290361E 04	2.611579E 00	7.084800E 05	LARGE ENG, NO. 1
26	9.063074E-01	4.153091E 04	0.0	0.0	3.125040E 01	1.362900E 06	LARGE ENG, NO. 1
27	9.063074E-01	4.153091E 04	0.0	0.0	3.125040E 01	1.362900E 06	LARGE ENG, NO. 1
28	9.063074E-01	4.153091E 04	0.0	0.0	3.125040E 01	1.362900E 06	LARGE ENG, NO. 1
29	9.063074E-01	4.545449E 04	0.0	0.0	3.125040E 01	1.362900E 06	LARGE ENG, NO. 1
30	1.000000E 00	0.0	2.711000E-01	1.039449E 04	2.026918E 00	6.625600E 05	LARGE ENG, NO. 1
31	1.000000E 00	0.0	3.471993E-01	1.274462E 04	2.035144E 00	6.625600E 05	LARGE ENG, NO. 1
32	1.000000E 00	0.0	5.794000E-01	3.958872E 04	3.954212E 00	1.460250E 06	LARGE ENG, NO. 1
33	1.000000E 00	0.0	5.793000E-01	3.858356E 04	3.958317E 00	1.460250E 06	LARGE ENG, NO. 1
34	1.000000E 00	0.0	4.096993E-01	1.382075E 04	2.377052E 00	4.592000E 05	LARGE ENG, NO. 1
35	1.000000E 00	0.0	4.096993E-01	1.393709E 04	2.404605E 00	4.592000E 05	LARGE ENG, NO. 1
36	1.000000E 00	0.0	3.426993E-01	1.328154E 04	2.384987E 00	4.592000E 05	LARGE ENG, NO. 1
37	1.000000E 00	0.0	4.568000E-01	1.902991E 04	4.113285E 00	8.360000E 05	LARGE ENG, NO. 2
38	1.000000E 00	0.0	4.076993E-01	1.580411E 04	4.113285E 00	8.360000E 05	LARGE ENG, NO. 2
39	9.396926E-01	3.146186E 04	0.0	0.0	1.519172E 01	8.800000E 05	LARGE ENG, NO. 2
40	9.396926E-01	3.146186E 04	0.0	0.0	1.519172E 01	8.800000E 05	LARGE ENG, NO. 2
41	9.396926E-01	3.146136E 04	0.0	0.0	1.519172E 01	8.800000E 05	LARGE ENG, NO. 2
42	9.702247E-01	1.101410E 04	0.0	0.0	5.602039E 00	1.408750E 06	LARGE ENG, NO. 2
43	9.702247E-01	1.355026E 04	0.0	0.0	5.602482E 00	1.408750E 06	LARGE ENG, NO. 2
44	9.396926E-01	3.413323E 04	0.0	0.0	1.805780E 01	1.531250E 06	LARGE ENG, NO. 2
45	9.396926E-01	3.417466E 04	0.0	0.0	1.805780E 01	1.531250E 06	LARGE ENG, NO. 2
46	9.396926E-01	3.417466E 04	0.0	0.0	1.805780E 01	1.531250E 06	LARGE ENG, NO. 2
47	1.000000E 00	0.0	3.187000E-01	8.820719E 03	1.293426E 00	7.040000E 05	LARGE ENG, NO. 2
48	1.000000E 00	0.0	5.087000E-01	2.473981E 04	5.856403E 00	1.592500E 06	LARGE ENG, NO. 2
49	1.000000E 00	0.0	4.226993E-01	1.537454E 04	3.465134E 00	7.480000E 05	LARGE ENG, NO. 2
50	1.000000E 00	0.0	3.407993E-01	1.394249E 04	3.425579E 00	7.480000E 05	LARGE ENG, NO. 2

TABLE XXXVI. CALCULATED BEARING CHARACTERISTICS (CONTINUED)

ROW	FL RT.SD	FL CG.VL	CAGE RUB VEL ON OUTER RACE	CAGE RUB VEL. ON INNER RACE	D/E	ND**2	ROW TITLE
1	9.000781E 04	7.422672E 03	0.0	7.706719E 03	8.873236E-02	0.0	SMALL ENG, NO. 2
2	8.999846E 04	7.410121E 03	0.0	7.711152E 03	9.874148E-02	0.0	SMALL ENG, NO. 2
3	5.700525E 04	9.860350E 03	0.0	9.537922E 03	1.380747E-01	7.049592E 00	SMALL ENG, NO. 2
4	9.523610E 04	7.353690E 03	0.0	7.926660E 03	9.393282E-02	0.0	SMALL ENG, NO. 2
5	7.401863E 04	4.903422E 03	0.0	5.156137E 03	1.075268E-01	0.0	SMALL ENG, NO. 1
6	6.493759E 04	4.250860E 03	0.0	4.418203E 03	1.239219E-01	1.250000E 00	SMALL ENG, NO. 1
7	6.101055E 04	4.242313E 03	0.0	4.469996E 03	1.316807E-01	1.269779E 00	SMALL ENG, NO. 1
8	9.407881E 04	1.257672E 04	0.0	1.348215E 04	1.820831E-01	3.500000E 00	SMALL ENG, NO. 1
9	9.841650E 04	1.289272E 04	0.0	1.395578E 04	1.773866E-01	3.750000E 00	SMALL ENG, NO. 1
10	1.701268E 05	1.579006E 04	0.0	1.476627E 04	1.046660E-01	0.0	SMALL ENG, NO. 1
11	1.573503E 05	1.306154E 04	0.0	1.471536E 04	1.129290E-01	0.0	SMALL ENG, NO. 1
12	4.879457E 04	6.783211E 03	0.0	7.247727E 03	1.634827E-01	4.229413E 00	SMALL ENG, NO. 1
13	4.879457E 04	6.783211E 03	0.0	7.247727E 03	1.634827E-01	4.229413E 00	SMALL ENG, NO. 1
14	4.870381E 04	6.783105E 03	0.0	6.999900E 03	1.634852E-01	4.229413E 00	SMALL ENG, NO. 1
15	3.601607E 04	5.197305E 03	-5.039137E 03	0.0	9.032506E-02	0.0	LARGE ENG, NO. 1
16	3.288624E 04	5.205194E 03	-5.039664E 03	0.0	3.168912E-02	0.0	LARGE ENG, NO. 1
17	2.588685E 04	5.506453E 03	0.0	5.036180E 03	1.250769E-01	1.386328E 01	LARGE ENG, NO. 1
18	2.598685E 04	5.506453E 03	0.0	5.043246E 03	1.250769E-01	1.386328E 01	LARGE ENG, NO. 1
19	2.570444E 04	5.496737E 03	0.0	5.032484E 03	1.255136E-01	1.452344E 01	LARGE ENG, NO. 1
20	2.588685E 04	5.506453E 03	0.0	5.037508E 03	1.250769E-01	1.386328E 01	LARGE ENG, NO. 1
21	1.721200E 04	2.112460E 03	0.0	-2.010755E 03	9.159648E-02	4.175694E 00	LARGE ENG, NO. 1
22	1.612257E 04	2.110463E 03	0.0	-2.223086E 03	9.769249E-02	4.750000E 00	LARGE ENG, NO. 1
23	1.013461E 04	1.819116E 03	0.0	-2.141145E 03	7.315642E-02	0.0	LARGE ENG, NO. 1
24	1.069605E 04	1.318574E 03	0.0	-1.896384E 03	7.142276E-02	0.0	LARGE ENG, NO. 1
25	1.002605E 04	1.919073E 03	0.0	-1.896346E 03	7.331771E-02	0.0	LARGE ENG, NO. 1
26	3.612986E 04	9.367421E 03	0.0	9.512359E 03	1.327716E-01	1.757813E 01	LARGE ENG, NO. 1
27	3.625669E 04	9.900707E 03	0.0	9.518121E 03	1.322919E-01	1.757813E 01	LARGE ENG, NO. 1
28	3.626479E 04	3.901230E 03	0.0	9.510773E 03	1.322845E-01	1.757813E 01	LARGE ENG, NO. 1
29	3.303182E 04	9.883344E 03	0.0	9.432254E 03	1.411034E-01	1.900000E 01	LARGE ENG, NO. 1
30	2.202102E 04	1.930302E 03	0.0	-1.969610E 03	5.892776E-02	0.0	LARGE ENG, NO. 1
31	2.258870E 04	1.930330E 03	0.0	-1.966741E 03	6.881833E-02	0.0	LARGE ENG, NO. 1
32	5.170821E 04	9.075215E 03	0.0	9.047145E 03	9.315497E-02	0.0	LARGE ENG, NO. 1
33	5.170821E 04	9.074215E 03	0.0	9.052953E 03	9.315497E-02	0.0	LARGE ENG, NO. 1
34	3.145384E 04	3.010658E 03	0.0	3.133605E 03	1.025315E-01	0.0	LARGE ENG, NO. 1
35	3.141828E 04	3.010597E 03	0.0	3.134872E 03	1.026444E-01	0.0	LARGE ENG, NO. 1
36	2.315554E 04	3.005990E 03	0.0	3.155642E 03	1.111111E-01	0.0	LARGE ENG, NO. 1
37	4.477075E 04	5.304145E 03	0.0	5.306121E 03	9.374002E-02	0.0	LARGE ENG, NO. 2
38	5.304210E 04	5.314360E 03	0.0	5.366121E 03	9.239965E-02	0.0	LARGE ENG, NO. 2
39	2.807825E 04	5.772520E 03	0.0	6.517664E 03	1.534466E-01	1.188281E 01	LARGE ENG, NO. 2
40	2.764445E 04	5.880316E 03	0.0	6.329375E 03	1.557543E-01	1.188281E 01	LARGE ENG, NO. 2
41	2.764418E 04	5.890256E 03	0.0	6.260070E 03	1.557558E-01	1.188281E 01	LARGE ENG, NO. 2
42	5.404441E 04	8.990277E 03	0.0	9.415320E 03	1.101768E-01	6.250000E 00	LARGE ENG, NO. 2
43	5.530120E 04	2.049664E 03	0.0	2.437898E 03	1.094820E-01	5.859375E 00	LARGE ENG, NO. 2
44	4.446177E 04	3.921291E 03	0.0	1.066773E 04	1.293790E-01	1.396329E 01	LARGE ENG, NO. 2
45	4.403577E 04	3.792379E 03	0.0	1.054910E 04	1.310315E-01	1.396329E 01	LARGE ENG, NO. 2
46	4.403577E 04	3.792379E 03	0.0	1.030418E 04	1.310315E-01	1.396329E 01	LARGE ENG, NO. 2
47	2.551643E 04	1.653370E 03	0.0	-1.707398E 03	6.729728E-02	0.0	LARGE ENG, NO. 2
48	7.454075E 04	9.719527E 03	0.0	9.715840E 03	8.161259E-02	0.0	LARGE ENG, NO. 2
49	5.026910E 04	4.736352E 03	0.0	4.907031E 03	9.686835E-02	0.0	LARGE ENG, NO. 2
50	4.545580E 04	4.798227E 03	0.0	4.901492E 03	9.397887E-02	0.0	LARGE ENG, NO. 2

TABLE XXXVI. CALCULATED BEARING CHARACTERISTICS (CONTINUED)

ROW	NDL	ROLL.L/D	PITCH LINE VELOCITY	CAGE SPD	BALL CF.	ROLL.CF.	ROW TITLE
1	3.319261E 00	1.374370E 00	6.917773E 03	7.335703E 03	0.0	2.589343E 01	SMALL ENG, NO. 2
2	2.932203E 00	1.124661E 00	6.306137E 03	7.335429E 03	0.0	2.104326E 01	SMALL ENG, NO. 2
3	0.0	0.0	7.969203E 03	7.036070E 03	3.306146E 01	0.0	SMALL ENG, NO. 2
4	6.018138E 00	1.349861E 00	7.745547E 03	7.374340E 03	0.0	2.715867E 01	SMALL ENG, NO. 2
5	1.250000E 00	1.000000E 00	4.427363E 03	7.273655E 03	0.0	6.062020E 00	SMALL ENG, NO. 1
6	0.0	0.0	3.821073E 03	7.234660E 03	3.449172E 00	0.0	SMALL ENG, NO. 1
7	0.0	0.0	3.700002E 03	7.177352E 03	4.093505E 00	0.0	SMALL ENG, NO. 1
8	0.0	0.0	1.077135E 04	1.498305E 04	1.620275E 02	0.0	SMALL ENG, NO. 1
9	0.0	0.0	1.106917E 04	1.505392E 04	1.672617E 02	0.0	SMALL ENG, NO. 1
10	2.203767E 00	9.773948E-01	1.429516E 04	1.611637E 04	0.0	1.206416E 02	SMALL ENG, NO. 1
11	2.448407E 00	1.161699E 00	1.354497E 04	1.596728E 04	0.0	1.091201E 02	SMALL ENG, NO. 1
12	0.0	0.0	5.920773E 03	6.962834E 03	4.957422E 01	0.0	SMALL ENG, NO. 1
13	0.0	0.0	5.920773E 03	6.962334E 03	4.957422E 01	0.0	SMALL ENG, NO. 1
14	0.0	0.0	5.922564E 03	6.962316E 03	4.957315E 01	0.0	SMALL ENG, NO. 1
15	7.803356E 00	1.000000E 00	4.745932E 03	2.983732E 03	0.0	2.969571E 01	LARGE ENG, NO. 1
16	7.081482E 00	1.370611E 00	4.812084E 03	3.012059E 03	0.0	2.315919E 01	LARGE ENG, NO. 1
17	0.0	0.0	4.345805E 03	2.909184E 03	4.196370E 01	0.0	LARGE ENG, NO. 1
18	0.0	0.0	4.345805E 03	2.908184E 03	4.196370E 01	0.0	LARGE ENG, NO. 1
19	0.0	0.0	4.924602E 03	2.906987E 03	4.169307E 01	0.0	LARGE ENG, NO. 1
20	0.0	0.0	4.345805E 03	2.909184E 03	4.196370E 01	0.0	LARGE ENG, NO. 1
21	0.0	0.0	1.102355E 04	8.273281E 03	7.600363E 01	0.0	LARGE ENG, NO. 1
22	0.0	0.0	1.110530E 04	8.288051E 03	3.240617E 01	0.0	LARGE ENG, NO. 1
23	4.286200E 00	1.094871E 00	1.049029E 04	9.070465E 03	0.0	5.283713E 01	LARGE ENG, NO. 1
24	4.176006E 00	3.775948E-01	1.067782E 04	8.069023E 03	0.0	4.429785E 01	LARGE ENG, NO. 1
25	4.123684E 00	9.7415[illegible]E-01	1.069129E 04	8.079591E 03	0.0	4.776195E 01	LARGE ENG, NO. 1
26	0.0	0.0	7.315172E 03	4.281781E 03	2.262883E 02	0.0	LARGE ENG, NO. 1
27	0.0	0.0	7.347703E 03	4.283398E 03	2.253240E 02	0.0	LARGE ENG, NO. 1
28	0.0	0.0	7.949305E 03	4.293934E 03	2.253405E 02	0.0	LARGE ENG, NO. 1
29	0.0	0.0	7.874121E 03	4.245027E 03	2.685349E 02	0.0	LARGE ENG, NO. 1
30	3.482513E 00	5.743206E-01	9.878703E 03	8.256922E 03	0.0	2.994486E 01	LARGE ENG, NO. 1
31	4.172467E 00	1.240699E 00	9.873582E 03	8.256746E 03	0.0	3.792549E 01	LARGE ENG, NO. 1
32	1.230400E 01	7.631946E-01	8.302770E 03	4.414066E 03	0.0	1.309178E 02	LARGE ENG, NO. 1
33	1.254205E 01	1.000000E 00	8.302770E 03	4.414066E 03	0.0	1.323802E 02	LARGE ENG, NO. 1
34	3.000606E 00	1.262592E 00	2.739677E 03	2.943695E 03	0.0	5.963024E 00	LARGE ENG, NO. 1
35	4.003900E 00	1.261204E 00	2.730336E 03	2.943326E 03	0.0	5.874467E 00	LARGE ENG, NO. 1
36	3.719001E 00	1.000000E 00	2.704573E 03	2.915555E 03	0.0	5.797160E 00	LARGE ENG, NO. 1
37	5.743176E 00	1.191713E 00	4.951746E 03	3.983742E 03	0.0	2.238828E 01	LARGE ENG, NO. 2
38	4.015246E 00	1.198589E 00	4.002876E 03	4.037494E 03	0.0	1.604633E 01	LARGE ENG, NO. 2
39	0.0	0.0	5.212918E 03	3.765551E 03	3.447799E 01	0.0	LARGE ENG, NO. 2
40	0.0	0.0	5.129551E 03	3.756010E 03	4.300119E 01	0.0	LARGE ENG, NO. 2
41	0.0	0.0	5.123489E 03	3.756904E 03	9.300014E 01	0.0	LARGE ENG, NO. 2
42	0.0	0.0	8.114227E 03	5.463711E 03	3.693256E 01	0.0	LARGE ENG, NO. 2
43	0.0	0.0	9.171949E 03	5.467883E 03	3.761795E 01	0.0	LARGE ENG, NO. 2
44	0.0	0.0	8.845836E 03	5.390344E 03	2.050347E 02	0.0	LARGE ENG, NO. 2
45	0.0	0.0	9.718836E 03	5.370832E 03	2.017337E 02	0.0	LARGE ENG, NO. 2
46	0.0	0.0	9.718836E 03	5.370832E 03	2.017337E 02	0.0	LARGE ENG, NO. 2
47	3.318279E 00	1.423492E 00	1.030752E 04	1.064109E 04	0.0	2.997849E 01	LARGE ENG, NO. 2
48	7.303670E 00	1.152027E 00	9.286141E 03	5.625121E 03	0.0	8.664594E 01	LARGE ENG, NO. 2
49	4.678922E 00	1.352127E 00	4.611156E 03	4.017777E 03	0.0	1.299824E 01	LARGE ENG, NO. 2
50	3.340123E 00	3.790330E-01	4.377293E 03	3.985233E 03	0.0	1.257293E 01	LARGE ENG, NO. 2

TABLE XXXVI. CALCULATED BEARING CHARACTERISTICS (CONTINUED)

ROW	PITCH DIA (IN) X SHAFT SPD	E NM	E IN MM	PITCH DIA (MM) X SHAFT SPD	E NM	ID IN MM	ROW TITLE
1	5.715508E 04	0.0	9.017017E 01	1.451739E 06	0.0	7.500000E 01	SMALL ENG, NO. 2
2	5.705930E 04	0.0	9.001778E 01	1.449296E 06	0.0	7.500000E 01	SMALL ENG, NO. 2
3	6.877930E 04	0.0	1.085090E 02	1.746994E 06	0.0	8.500000E 01	SMALL ENG, NO. 2
4	6.042329E 04	0.0	9.532637E 01	1.534754E 06	0.0	8.000000E 01	SMALL ENG, NO. 2
5	3.789520E 04	0.0	5.005511E 01	9.625383E 05	0.0	4.529999E 01	SMALL ENG, NO. 1
6	3.288361E 04	0.0	5.126205E 01	8.352454E 05	0.0	4.000000E 01	SMALL ENG, NO. 1
7	3.287700E 04	0.0	5.123187E 01	8.350795E 05	0.0	4.000000E 01	SMALL ENG, NO. 1
8	9.885504E 04	0.0	6.974852E 01	2.510946E 06	0.0	5.000000E 01	SMALL ENG, NO. 1
9	1.011311E 05	0.0	7.135391E 01	2.568736E 06	0.0	5.000000E 01	SMALL ENG, NO. 1
10	1.218851E 05	0.0	8.500633E 01	3.095883E 06	0.0	5.729999E 01	SMALL ENG, NO. 1
11	1.080352E 05	0.0	7.622554E 01	2.744119E 06	0.0	5.729999E 01	SMALL ENG, NO. 1
12	5.294321E 04	0.0	8.250061E 01	1.344760E 06	0.0	6.029999E 01	SMALL ENG, NO. 1
13	5.294321E 04	0.0	8.250043E 01	1.344760E 06	0.0	6.000000E 01	SMALL ENG, NO. 1
14	5.294230E 04	0.0	8.249936E 01	1.344739E 06	0.0	6.029999E 01	SMALL ENG, NO. 1
15	4.003174E 04	0.0	1.550013E 02	1.016930E 06	0.0	1.300000E 02	LARGE ENG, NO. 1
16	4.003174E 04	0.0	1.550013E 02	1.016980E 06	0.0	1.300000E 02	LARGE ENG, NO. 1
17	4.261375E 04	0.0	1.649987E 02	1.082391E 06	0.0	1.300000E 02	LARGE ENG, NO. 1
18	4.261375E 04	0.0	1.649987E 02	1.082391E 06	0.0	1.300000E 02	LARGE ENG, NO. 1
19	4.245550E 04	0.0	1.644247E 02	1.078625E 06	0.0	1.300000E 02	LARGE ENG, NO. 1
20	4.261375E 04	0.0	1.649987E 02	1.082391E 06	0.0	1.300000E 02	LARGE ENG, NO. 1
21	0.0	4.337418E 04	1.300000E 02	0.0	3.417273E 09	1.100000E 02	LARGE ENG, NO. 1
22	0.0	4.341906E 04	1.300000E 02	0.0	3.420892E 09	1.100000E 02	LARGE ENG, NO. 1
23	0.0	4.003434E 04	1.259995E 02	0.0	2.862501E 09	1.080000E 02	LARGE ENG, NO. 1
24	0.0	4.002223E 04	1.259995E 02	0.0	2.861636E 09	1.080000E 02	LARGE ENG, NO. 1
25	0.0	4.003547E 04	1.259995E 02	0.0	2.862592E 09	1.080000E 02	LARGE ENG, NO. 1
26	6.873881E 04	0.0	1.793698E 02	1.745969E 06	0.0	1.400000E 02	LARGE ENG, NO. 1
27	6.898800E 04	0.0	1.800000E 02	1.752299E 06	0.0	1.400000E 02	LARGE ENG, NO. 1
28	6.899194E 04	0.0	1.800102E 02	1.752398E 06	0.0	1.400000E 02	LARGE ENG, NO. 1
29	6.899194E 04	0.0	1.800102E 02	1.752398E 06	0.0	1.400000E 02	LARGE ENG, NO. 1
30	0.0	3.773613E 04	1.160782E 02	0.0	3.043075E 09	1.010000E 02	LARGE ENG, NO. 1
31	0.0	3.773332E 04	1.160792E 02	0.0	3.043010E 09	1.010000E 02	LARGE ENG, NO. 1
32	6.994400E 04	0.0	1.824943E 02	1.776581E 06	0.0	1.500000E 02	LARGE ENG, NO. 1
33	6.994400E 04	0.0	1.824943E 02	1.776591E 06	0.0	1.500000E 02	LARGE ENG, NO. 1
34	2.324404E 04	0.0	8.999998E 01	5.903999E 05	0.0	7.000000E 01	LARGE ENG, NO. 1
35	2.324404E 04	0.0	8.999998E 01	5.903999E 05	0.0	7.000000E 01	LARGE ENG, NO. 1
36	2.324404E 04	0.0	8.999998E 01	5.903999E 05	0.0	7.000000E 01	LARGE ENG, NO. 1
37	4.087500E 04	0.0	1.170832E 02	1.038252E 06	0.0	9.500000E 01	LARGE ENG, NO. 2
38	4.087500E 04	0.0	1.170832E 02	1.038252E 06	0.0	9.500000E 01	LARGE ENG, NO. 2
39	4.659600E 04	0.0	1.344933E 02	1.183540E 06	0.0	1.000000E 02	LARGE ENG, NO. 2
40	4.509564E 04	0.0	1.325006E 02	1.164005E 06	0.0	1.000000E 02	LARGE ENG, NO. 2
41	4.509519E 04	0.0	1.324904E 02	1.165994E 06	0.0	1.000000E 02	LARGE ENG, NO. 2
42	6.949064E 04	0.0	1.440849E 02	1.765066E 06	0.0	1.150000E 02	LARGE ENG, NO. 2
43	6.993156E 04	0.0	1.450012E 02	1.776265E 06	0.0	1.150000E 02	LARGE ENG, NO. 2
44	7.700904E 04	0.0	1.595123E 02	1.956025E 06	0.0	1.250000E 02	LARGE ENG, NO. 2
45	7.596075E 04	0.0	1.575006E 02	1.929382E 06	0.0	1.250000E 02	LARGE ENG, NO. 2
46	7.596075E 04	0.0	1.575006E 02	1.929382E 06	0.0	1.250000E 02	LARGE ENG, NO. 2
47	0.0	3.027200E 04	9.398018E 01	0.0	3.450174E 09	8.000000E 01	LARGE ENG, NO. 2
48	7.474944E 04	0.0	1.549911E 02	1.898641E 06	0.0	1.300000E 02	LARGE ENG, NO. 2
49	3.690465E 04	0.0	1.065202E 02	9.373776E 05	0.0	8.500000E 01	LARGE ENG, NO. 2
50	3.690465E 04	0.0	1.065202E 02	9.373776E 05	0.0	8.500000E 01	LARGE ENG, NO. 2

TABLE XXXVI. CALCULATED BEARING CHARACTERISTICS (CONTINUED)

ROW	E IN IN.	ROW TITLE
1	3.5400000E 00	SMALL ENG, NO. 2
2	3.5440000E 00	SMALL ENG, NO. 2
3	4.2719990E 00	SMALL ENG, NO. 2
4	3.7520000E 00	SMALL ENG, NO. 2
5	2.3250000E 00	SMALL ENG, NO. 1
6	2.0174000E 00	SMALL ENG, NO. 1
7	2.0169000E 00	SMALL ENG, NO. 1
8	2.7450000E 00	SMALL ENG, NO. 1
9	2.9031500E 00	SMALL ENG, NO. 1
10	3.3956000E 00	SMALL ENG, NO. 1
11	3.3009990E 00	SMALL ENG, NO. 1
12	3.2490500E 00	SMALL ENG, NO. 1
13	3.2490500E 00	SMALL ENG, NO.
14	3.2470000E 00	SMALL ENG, NO. 1
15	6.1024000E 00	LARGE ENG, NO. 1
16	6.1024000E 00	LARGE ENG, NO. 1
17	6.4059000E 00	LARGE ENG, NO. 1
18	6.4950000E 00	LARGE ENG, NO. 1
19	6.4733000E 00	LARGE ENG, NO. 1
20	6.4959000E 00	LARGE ENG, NO. 1
21	5.1190000E 00	LARGE ENG, NO. 1
22	5.1130000E 00	LARGE ENG, NO. 1
23	4.2634000E 00	LARGE ENG, NO. 1
24	4.9634000E 00	LARGE ENG, NO. 1
25	4.2634000E 00	LARGE ENG, NO. 1
26	7.0610000E 00	LARGE ENG, NO. 1
27	7.2865000E 00	LARGE ENG, NO. 1
28	7.0870000E 00	LARGE ENG, NO. 1
29	7.0870000E 00	LARGE ENG, NO. 1
30	4.5700000E 00	LARGE ENG, NO. 1
31	4.5700000E 00	LARGE ENG, NO. 1
32	7.1847000E 00	LARGE ENG, NO. 1
33	7.1847000E 00	LARGE ENG, NO. 1
34	3.5433000E 00	LARGE ENG, NO. 1
35	3.5433000E 00	LARGE ENG, NO. 1
36	3.5433000E 00	LARGE ENG, NO. 1
37	4.4450000E 00	LARGE ENG, NO. 2
38	4.4450000E 00	LARGE ENG, NO. 2
39	5.2049000E 00	LARGE ENG, NO. 2
40	5.2165500E 00	LARGE ENG, NO. 2
41	5.2144900E 00	LARGE ENG, NO. 2
42	5.4727000E 00	LARGE ENG, NO. 2
43	5.7036000E 00	LARGE ENG, NO. 2
44	6.2800000E 00	LARGE ENG, NO. 2
45	6.2003000E 00	LARGE ENG, NO. 2
46	6.2038000E 00	LARGE ENG, NO. 2
47	3.7000000E 00	LARGE ENG, NO. 2
48	6.1010000E 00	LARGE ENG, NO. 2
49	4.1027000E 00	LARGE ENG, NO. 2
50	4.1027000E 00	LARGE ENG, NO. 2

TABLE XXXVI. CALCULATED BEARING CHARACTERISTICS (CONTINUED)

*** CASH PROGRAM OUTPUT ***

MAINSHAFT BEARING CHARACTERISTICS

ROW	COS ALPH	BALL CAP	EFF.LENG	ROLL.CAP	APPR.WT.	DN	ROW TITLE
51	9.396926E-01	*8.000044E04	0.0	0.0	5.070633E 01	7.858200E 05	LARGE ENG, NO. 3
52	9.396926E-01	*4.501866E04	0.0	0.0	3.362395E 01	1.778480E 06	LARGE ENG, NO. 3
53	9.396926E-01	*4.501866E04	0.0	0.0	3.362395E 01	1.778480E 06	LARGE ENG, NO. 3
54	1.000000E 00	0.0	9.156000E-01	7.492450E 04	2.341425E 01	1.859740E 06	LARGE ENG, NO. 3
55	1.000000E 00	0.0	6.386999E-01	4.402724E 04	1.118479E 01	6.174300E 05	LARGE ENG, NO. 3
56	1.000000E 00	0.0	6.000000E-01	4.820791E 04	1.119118E 01	6.174300E 05	LARGE ENG, NO. 3
57	1.000000E 00	0.0	3.497033E-01	1.373689E 04	3.702299E 00	1.000160E 06	LARGE ENG, NO. 4
58	1.000000E 00	0.0	3.339999E-01	1.365965E 04	3.702299E 00	1.000160E 06	LARGE ENG, NO. 4
59	9.063074E-01	1.286319E 04	0.0	0.0	4.665859E 00	1.158080E 06	LARGE ENG, NO. 4
60	9.063074E-01	1.286319E 04	0.0	0.0	4.665859E 00	1.158080E 06	LARGE ENG, NO. 4
61	1.000000E 00	0.0	3.105000E-01	1.220969E 04	2.496840E 00	1.476000E 06	LARGE ENG, NO. 4
62	1.000000E 00	0.0	3.239999E-01	1.233470E 04	2.542974E 00	1.476000E 06	LARGE ENG, NO. 4
63	1.000000E 00	0.0	3.182999E-01	1.244758E 04	2.507442E 00	1.476000E 06	LARGE ENG, NO. 4
64	9.063074E-01	1.708804E 04	0.0	0.0	7.989491E 00	1.667880E 06	LARGE ENG, NO. 4
65	9.063074E-01	1.708804E 04	0.0	0.0	7.989491E 00	1.667880E 06	LARGE ENG, NO. 4
66	9.063074E-01	1.708804E 04	0.0	0.0	7.563324E 00	1.667880E 06	LARGE ENG, NO. 4
67	1.000000E 00	0.0	2.807000E-01	9.058967E 03	1.709018E 00	8.317120E 05	LARGE ENG, NO. 4
68	1.000000E 00	0.0	3.015000E-01	1.039536E 04	1.707596E 00	8.317120E 05	LARGE ENG, NO. 4
69	1.000000E 00	0.0	3.146999E-01	9.591656E 03	1.709018E 00	8.317120E 05	LARGE ENG, NO. 4
70	1.000000E 00	0.0	3.306000E-01	2.048909E 04	4.753979E 00	1.937620E 06	LARGE ENG, NO. 4
71	1.000000E 00	0.0	4.024000E-01	2.051500E 04	4.742584E 00	1.937620E 06	LARGE ENG, NO. 4
72	1.000000E 00	0.0	3.000000E-01	7.981742E 03	2.898144E 00	6.943200E 05	LARGE ENG, NO. 4
73	1.000000E 00	0.0	2.650000E-01	8.315293E 03	2.891986E 00	6.943200E 05	LARGE ENG, NO. 4
74	1.000000E 00	0.0	3.072999E-01	1.073233E 04	2.893526E 00	6.943200E 05	LARGE ENG, NO. 4
75	9.063074E-01	1.373627E 04	0.0	0.0	9.029900E 00	1.000000E 06	LARGE ENG, NO. 5
76	9.063074E-01	2.124793E 04	0.0	0.0	9.862990E 00	1.761750E 06	LARGE ENG, NO. 5
77	1.000000E 00	0.0	6.427000E-01	4.238830E 04	9.950960E 00	2.126250E 06	LARGE ENG, NO. 5
78	1.000000E 00	0.0	5.900000E-01	3.602650E 04	1.099313E 01	2.065500E 06	LARGE ENG, NO. 5
79	1.000000E 00	0.0	3.777000E-01	1.229609E 04	1.577800E 00	0.0	LARGE ENG, NO. 5
80	1.000000E 00	0.0	2.730000E-01	8.639531E 03	1.577800E 00	0.0	LARGE ENG, NO. 5
81	1.000000E 00	0.0	5.196000E-01	2.309146E 04	5.357975E 00	1.013000E 06	LARGE ENG, NO. 6
82	8.571668E-01	1.529260E 04	0.0	0.0	7.059311E 00	1.114300E 06	LARGE ENG, NO. 6
83	9.765458E-01	2.412579E 04	0.0	0.0	1.371417E 01	2.046000E 06	LARGE ENG, NO. 6
84	1.000000E 00	0.0	5.590000E-01	3.813013E 04	1.036171E 01	2.178000E 06	LARGE ENG, NO. 6
85	1.000000E 00	0.0	5.489000E-01	3.754620E 04	1.036171E 01	2.178000E 06	LARGE ENG, NO. 6
86	1.000000E 00	0.0	3.681000E-01	1.454901E 04	5.596378E 00	0.0	LARGE ENG, NO. 6
87	1.000000E 00	0.0	3.760000E-01	1.507135E 04	5.596378E 00	0.0	LARGE ENG, NO. 6
88	1.000000E 00	0.0	3.681000E-01	1.454901E 04	5.596374E 00	0.0	LARGE ENG, NO. 6
89	9.396926E-01	6.043875E 03	0.0	0.0	1.171696E 00	9.900000E 05	SMALL ENG, NO. 3
90	1.000000E 00	0.0	2.665000E-01	6.073074E 03	6.218579E-01	1.320000E 06	SMALL ENG, NO. 3
91	1.000000E 00	0.0	2.665000E-01	6.073074E 03	6.218579E-01	1.500000E 06	SMALL ENG, NO. 3
92	9.396926E-01	6.043875E 03	0.0	0.0	1.311735E 00	1.125000E 06	SMALL ENG, NO. 3

TABLE XXXVI. CALCULATED BEARING CHARACTERISTICS (CONTINUED)

ROW	FL.RT.SD	EL-CG.VL	CAGE RUB VEL. ON OUTER RACE	CAGE RUB VEL. ON INNER RACE	D/E	ND**2	ROW TITLE
51	1.319083E 04	5.391781E 03	0.0	5.945669E 03	1.395089E-01	4.882813E 01	LARGE ENG. NO. 3
52	3.781427E 04	1.113724E 04	0.0	1.191305E 04	1.058335E-01	3.164063E 01	LARGE ENG, NO. 3
53	3.781427E 04	1.113724E 04	0.0	1.167407E 04	1.058335E-01	3.164063E 01	LARGE ENG, NO. 3
54	4.754680E 04	1.127144E 04	0.0	1.164694E 04	9.440524E-02	0.0	LARGE ENG, NO. 3
55	2.036311E 04	3.770232E 03	0.0	3.764990E 03	3.109253E-02	0.0	LARGE ENG, NO. 3
56	1.044336E 04	3.776273E 03	0.0	3.781956E 03	9.525704E-02	0.0	LARGE ENG, NO. 3
57	6.008620E 04	6.122224E 03	0.0	6.393504E 03	9.694786E-02	0.0	LARGE ENG, NO. 4
58	6.126114E 04	6.209375E 03	0.0	6.419940E 03	9.530188E-02	0.0	LARGE ENG, NO. 4
59	4.676307E 04	7.240092E 03	0.0	7.534227E 03	1.176139E-01	8.593750E 00	LARGE ENG, NO. 4
60	4.612705E 04	7.220426E 03	0.0	7.705598E 03	1.179267E-01	8.593750E 00	LARGE ENG, NO. 4
61	9.782544E 04	9.073871E 03	0.0	9.662133E 03	7.501584E-02	0.0	LARGE ENG, NO. 4
62	1.035224E 05	9.079313E 03	0.0	9.747066E 03	7.092947E-02	0.0	LARGE ENG, NO. 4
63	9.782544E 04	9.073871E 03	0.0	9.695906E 03	7.501584E-02	0.0	LARGE ENG, NO. 4
64	5.512453E 04	1.083744E 04	0.0	1.163191E 04	1.318009E-01	1.125000E 01	LARGE ENG, NO. 4
65	5.415941E 04	1.102670E 04	0.0	1.172519E 04	1.296308E-01	1.125000E 01	LARGE ENG, NO. 4
66	5.455741E 04	1.110504E 04	0.0	1.153423E 04	1.287112E-01	1.125000E 01	LARGE ENG, NO. 4
67	2.825702E 04	2.038847E 03	0.0	-2.159194E 03	7.446635E-02	0.0	LARGE ENG, NO. 4
68	2.635102E 04	2.037185E 03	0.0	-2.150719E 03	7.978922E-02	0.0	LARGE ENG, NO. 4
69	2.781992E 04	2.038503E 03	0.0	-2.150173E 03	7.562916E-02	0.0	LARGE ENG, NO. 4
70	9.023300E 04	1.117043E 04	0.0	1.199734E 04	3.116835E-02	0.0	LARGE ENG, NO. 4
71	9.226700E 04	1.142342E 04	0.0	1.179849E 04	7.339494E-02	0.0	LARGE ENG, NO. 4
72	5.593619E 04	4.496456E 03	0.0	4.806572E 03	9.335703E-02	0.0	LARGE ENG, NO. 4
73	5.553780E 04	4.590035E 03	0.0	4.770092E 03	9.394568E-02	0.0	LARGE ENG, NO. 4
74	4.369647E 04	4.605620E 03	0.0	4.726509E 03	1.047605E-01	0.0	LARGE ENG, NO. 4
75	3.003649E 04	6.401895E 03	0.0	6.956328E 03	1.310315E-01	1.320313E 01	LARGE ENG, NO. 5
76	5.092752E 04	1.083202E 04	0.0	1.137444E 04	1.179245E-01	1.518359E 01	LARGE ENG, NO. 5
77	7.652700E 04	1.266738E 04	0.0	1.306019E 04	7.888955E-02	0.0	LARGE ENG, NO. 5
78	8.179469E 04	1.265402E 04	0.0	1.309594E 04	7.387495E-02	0.0	LARGE ENG, NO. 5
79	3.523505E 04	3.360845E 03	0.0	-3.457945E 03	1.118153E-01	0.0	LARGE ENG, NO. 5
80	3.628746E 04	3.363020E 03	0.0	-3.448952E 03	1.089230E-01	0.0	LARGE ENG, NO. 5
81	4.315329E 04	6.227130E 03	0.0	6.407304E 03	1.157983E-01	0.0	LARGE ENG, NO. 6
82	2.671660E 04	7.209301E 03	0.0	7.590430E 03	1.360717E-01	1.012500E 01	LARGE ENG, NO. 6
83	5.373442E 04	1.276306E 04	0.0	1.347724E 04	1.211499E-01	1.642578E 01	LARGE ENG, NO. 6
84	9.064488E 04	1.330259E 04	0.0	1.374166E 04	9.127737E-02	0.0	LARGE ENG, NO. 6
85	9.064488E 04	1.330259E 04	0.0	1.374166E 04	9.127737E-02	0.0	LARGE ENG, NO. 6
86	4.699123E 04	5.315652E 03	0.0	-5.613730E 03	1.068064E-01	0.0	LARGE ENG, NO. 6
87	4.603196E 04	5.313325E 03	0.0	-5.623609E 03	1.087546E-01	0.0	LARGE ENG, NO. 6
88	4.699123E 04	5.315652E 03	0.0	-5.613730E 03	1.068064E-01	0.0	LARGE ENG, NO. 6
89	5.092752E 04	9.317003E 03	0.0	9.775719E 03	2.596039E-01	2.919609E 00	SMALL ENG, NO. 3
90	1.164201E 05	9.006488E 03	0.0	9.627613E 03	1.388993E-01	0.0	SMALL ENG, NO. 3
91	1.323856E 05	1.023464E 04	0.0	1.094046E 04	1.388993E-01	0.0	SMALL ENG, NO. 3
92	6.709613E 04	3.451145E 03	0.0	1.110975E 04	2.596039E-01	2.919609E 00	SMALL ENG, NO. 3

TABLE XXXVI. CALCULATED BEARING CHARACTERISTICS (CONTINUED)

ROW	NDL	ROLL.L/D	PITCH LINE VEL.	CAGE SPD	BALL CF.	ROLL.CF.	ROW TITLE
51	0.0	0.0	4.766871E 03	1.625720E 03	2.374365E 02	0.0	LARGE ENG, NO. 3
52	0.0	0.0	1.012982E 04	3.640019E 03	4.216687E 02	0.0	LARGE ENG, NO. 3
53	0.0	0.0	1.012982E 04	3.640019E 03	4.216687E 02	0.0	LARGE ENG, NO. 3
54	2.600885E 01	9.012755E-01	1.032413E 04	3.709834E 03	0.0	3.410723E 02	LARGE ENG, NO. 3
55	1.406314E 01	1.000000E 00	3.463714E 03	1.700566E 03	0.0	2.525935E 01	LARGE ENG, NO. 3
56	1.444413E 01	1.025502E 00	3.447846E 03	1.697774E 03	0.0	2.935034E 01	LARGE ENG, NO. 3
57	3.347123E 00	9.793339E-01	5.697535E 03	4.806305E 03	0.0	1.972933E 01	LARGE ENG, NO. 4
58	3.301964E 00	1.094591E 00	5.720614E 03	4.814969E 03	0.0	2.098409E 01	LARGE ENG, NO. 4
59	0.0	0.0	6.547672E 03	4.702987E 03	6.033485E 01	0.0	LARGE ENG, NO. 4
60	0.0	0.0	6.523242E 03	4.701395E 03	6.013658E 01	0.0	LARGE ENG, NO. 4
61	3.692946E 00	9.779948E-01	8.440691E 03	6.825383E 03	0.0	3.019348E 01	LARGE ENG, NO. 4
62	3.859198E 00	1.074626E 00	8.477980E 03	6.856539E 03	0.0	2.829361E 01	LARGE ENG, NO. 4
63	3.765853E 00	1.000000E 00	8.440691E 03	6.826393E 03	0.0	3.097317E 01	LARGE ENG, NO. 4
64	0.0	0.0	9.691027E 03	6.499441E 03	2.131681E 02	0.0	LARGE ENG, NO. 4
65	0.0	0.0	9.967569E 03	6.513156E 03	2.177699E 02	0.0	LARGE ENG, NO. 4
66	0.0	0.0	9.944949E 03	6.519109E 03	2.196761E 02	0.0	LARGE ENG, NO. 4
67	2.914508E 00	1.199927E 00	1.240371E 04	1.289156E 04	0.0	4.905141E 01	LARGE ENG, NO. 4
68	3.274286E 00	1.173393E 00	1.241453E 04	1.281282E 04	0.0	5.790390E 01	LARGE ENG, NO. 4
69	2.970016E 00	1.263655E 00	1.240609E 04	1.290402E 04	0.0	5.302989E 01	LARGE ENG, NO. 4
70	6.584310E 00	3.834896E-01	1.033300E 04	6.789277E 03	0.0	8.751350E 01	LARGE ENG, NO. 4
71	6.494851E 00	1.000000E 00	1.059317E 04	6.796063E 03	0.0	9.132175E 01	LARGE ENG, NO. 4
72	2.703590E 00	1.111816E 00	4.213172E 03	4.772566E 03	0.0	8.402285E 00	LARGE ENG, NO. 4
73	2.381309E 00	1.000000E 00	4.186711E 03	4.759469E 03	0.0	7.519238E 00	LARGE ENG, NO. 4
74	3.012683E 00	1.000000E 00	4.172516E 03	4.712530E 03	0.0	1.053575E 01	LARGE ENG, NO. 4
75	0.0	0.0	5.722340E 03	3.524980E 03	9.682783E 01	0.0	LARGE ENG, NO. 5
76	0.0	0.0	9.784934E 03	5.425727E 03	2.287614E 02	0.0	LARGE ENG, NO. 5
77	1.464305E 01	1.144351E 00	1.174149E 04	5.595742E 03	0.0	2.290299E 02	LARGE ENG, NO. 5
78	1.250083E 01	1.119443E 00	1.178352E 04	5.676207E 03	0.0	1.944022E 02	LARGE ENG, NO. 5
79	3.467213E 00	1.262245E 00	3.793368E 03	4.447258E 03	0.0	1.228103E 01	LARGE ENG, NO. 5
80	2.504319E 00	1.000000E 00	3.774107E 03	4.435621E 03	0.0	8.947137E 00	LARGE ENG, NO. 5
81	6.510773E 00	1.071490E 00	5.590018E 03	4.478480E 03	0.0	5.403174E 01	LARGE ENG, NO. 6
82	0.0	0.0	6.456266E 03	4.476234E 03	3.787962E 01	0.0	LARGE ENG, NO. 6
83	0.0	0.0	1.147748E 04	5.869742E 03	4.021162E 02	0.0	LARGE ENG, NO. 6
84	1.240677E 01	1.000000E 00	1.230267E 04	6.063566E 03	0.0	2.246164E 02	LARGE ENG, NO. 6
85	1.240677E 01	1.000000E 00	1.230267E 04	6.063566E 03	0.0	2.246164E 02	LARGE ENG, NO. 6
86	4.126662E 00	1.000000E 00	5.351282E 03	5.605369E 03	0.0	3.265318E 01	LARGE ENG, NO. 6
87	4.279581E 00	1.000000E 00	5.961766E 03	5.615936E 03	0.0	3.455425E 01	LARGE ENG, NO. 6
88	4.126662E 00	1.000000E 00	5.351289E 03	5.605369E 03	0.0	3.265318E 01	LARGE ENG, NO. 6
89	0.0	0.0	6.686992E 03	1.247796E 04	1.002382E 02	0.0	SMALL ENG, NO. 3
90	1.637162E 00	1.173393E 00	7.908046E 03	1.429816E 04	0.0	4.990134E 01	SMALL ENG, NO. [illegible]
91	1.637162E 00	1.173393E 00	3.986641E 03	1.614564E 04	0.0	5.281680E 01	SMALL ENG, NO. 3
92	0.0	0.0	7.598855E 03	1.417250E 04	1.295689E 02	0.0	SMALL ENG, NO. 3

TABLE XXXVI. CALCULATED BEARING CHARACTERISTICS (CONTINUED)

ROW	PITCH DIA (IN.) X SHAFT SPD	E NM	E IN MM	PITCH DIA (MM) X SHAFT SPD	E NM	ID IN MM	ROW TITLE
51	4.191040E 04	0.0	2.844805E 02	1.064525E 06	0.0	2.100000E 02	LARGE ENG, NO. 3
52	8.593206E 04	0.0	2.700000E 02	2.182680E 06	0.0	2.200000E 02	LARGE ENG, NO. 3
53	8.593206E 04	0.0	2.700000E 02	2.182680E 06	0.0	2.200000E 02	LARGE ENG, NO. 3
54	8.672513E 04	0.0	2.724917E 02	2.202822E 06	0.0	2.350000E 02	LARGE ENG, NO. 3
55	2.911276E 04	0.0	1.376124E 02	7.394656E 05	0.0	1.650000E 02	LARGE ENG, NO. 3
56	2.911276E 04	0.0	1.376124E 02	7.394656E 05	0.0	1.650000E 02	LARGE ENG, NO. 3
57	4.767078E 04	0.0	1.150114E 02	1.210840E 06	0.0	9.500000E 01	LARGE ENG, NO. 4
58	4.777605E 04	0.0	1.152654E 02	1.213514E 06	0.0	9.500000E 01	LARGE ENG, NO. 4
59	5.594578E 04	0.0	1.349758E 02	1.421025E 06	0.0	1.100000E 02	LARGE ENG, NO. 4
60	5.579734E 04	0.0	1.344177E 02	1.417255E 06	0.0	1.100000E 02	LARGE ENG, NO. 4
61	6.971144E 04	0.0	1.199644E 02	1.770675E 06	0.0	1.000000E 02	LARGE ENG, NO. 4
62	6.971144E 04	0.0	1.199644E 02	1.770675E 06	0.0	1.000000E 02	LARGE ENG, NO. 4
63	6.971144E 04	0.0	1.199644E 02	1.770675E 06	0.0	1.000000E 02	LARGE ENG, NO. 4
64	8.399025E 04	0.0	1.445364E 02	2.133357E 06	0.0	1.130000E 02	LARGE ENG, NO. 4
65	8.541406E 04	0.0	1.469901E 02	2.169573E 06	0.0	1.130000E 02	LARGE ENG, NO. 4
66	8.600650E 04	0.0	1.480061E 02	2.184569E 06	0.0	1.130000E 02	LARGE ENG, NO. 4
67	0.0	4.737857E 04	9.400557E 01	0.0	5.097864E 09	7.900000E 01	LARGE ENG, NO. 4
68	0.0	4.742028E 04	9.400557E 01	0.0	5.097345E 09	7.900000E 01	LARGE ENG, NO. 4
69	0.0	4.738766E 04	9.400557E 01	0.0	5.093843E 09	7.900000E 01	LARGE ENG, NO. 4
70	8.590319E 04	0.0	1.479283E 02	2.181945E 06	0.0	1.245000E 02	LARGE ENG, NO. 4
71	8.792104E 04	0.0	1.511303E 02	2.233483E 06	0.0	1.245000E 02	LARGE ENG, NO. 4
72	3.550041E 04	0.0	8.564827E 01	9.017123E 05	0.0	6.500000E 01	LARGE ENG, NO. 4
73	3.530038E 04	0.0	8.516537E 01	8.966315E 05	0.0	6.500000E 01	LARGE ENG, NO. 4
74	3.560570E 04	0.0	8.590297E 01	9.043864E 05	0.0	6.500000E 01	LARGE ENG, NO. 4
75	4.999640E 04	0.0	1.575006E 02	1.269905E 06	0.0	1.250000E 02	LARGE ENG, NO. 5
76	8.371344E 04	0.0	1.750063E 02	2.126327E 06	0.0	1.450000E 02	LARGE ENG, NO. 5
77	9.738319E 04	0.0	2.035916E 02	2.473514E 06	0.0	1.750000E 02	LARGE ENG, NO. 5
78	9.720000E 04	0.0	2.032006E 02	2.468894E 06	0.0	1.700000E 02	LARGE ENG, NO. 5
79	2.600000E 04	0.0	9.255017E 01	6.604013E 05	0.0	6.500000E 01	LARGE ENG, NO. 5
80	2.600000E 04	0.0	9.255017E 01	6.604013E 05	0.0	6.500000E 01	LARGE ENG, NO. 5
81	4.821870E 04	0.0	1.202062E 02	1.224750E 06	0.0	1.000000E 02	LARGE ENG, NO. 6
82	5.583653E 04	0.0	1.400000E 02	1.419200E 06	0.0	1.100000E 02	LARGE ENG, NO. 6
83	9.974125E 04	0.0	1.900025E 02	2.533033E 06	0.0	1.550000E 02	LARGE ENG, NO. 6
84	1.023000E 05	0.0	1.969506E 02	2.598425E 06	0.0	1.550000E 02	LARGE ENG, NO. 6
85	1.023000E 05	0.0	1.969506E 02	2.598425E 06	0.0	1.650000E 02	LARGE ENG, NO. 6
86	4.107714E 04	0.0	1.029972E 02	1.043362E 06	0.0	8.000000E 01	LARGE ENG, NO. 6
87	4.107714E 04	0.0	1.029972E 02	1.043362E 06	0.0	8.000000E 01	LARGE ENG, NO. 6
88	4.107714E 04	0.0	1.029972E 02	1.043362E 06	0.0	8.000000E 01	LARGE ENG, NO. 6
89	6.755904E 04	0.0	5.199390E 01	1.715798E 06	0.0	3.000000E 01	SMALL ENG, NO. 3
90	7.015706E 04	0.0	5.400069E 01	1.782016E 06	0.0	4.000000E 01	SMALL ENG, NO. 3
91	7.972404E 04	0.0	5.400069E 01	2.025018E 06	0.0	4.000000E 01	SMALL ENG, NO. 3
92	7.676244E 04	0.0	5.199300E 01	1.949771E 06	0.0	3.000000E 01	SMALL ENG, NO. 3

TABLE XXXVI. CALCULATED BEARING CHARACTERISTICS (CONTINUED)

ROW	C IN IN.	ROW TITLE
51	1.120000E 01	LARGE ENG, NO. 3
52	1.062900E 01	LARGE ENG, NO. 3
53	1.062000E 01	LARGE ENG, NO. 3
54	1.077800E 01	LARGE ENG, NO. 3
55	7.780000E 00	LARGE ENG, NO. 3
56	7.780000E 00	LARGE ENG, NO. 3
57	4.528000E 00	LARGE ENG, NO. 4
58	4.537000E 00	LARGE ENG, NO. 4
59	5.313000E 00	LARGE ENG, NO. 4
60	5.300900E 00	LARGE ENG, NO. 4
61	4.723000E 00	LARGE ENG, NO. 4
62	4.723000E 00	LARGE ENG, NO. 4
63	4.723000E 00	LARGE ENG, NO. 4
64	5.409300E 00	LARGE ENG, NO. 4
65	5.787000E 00	LARGE ENG, NO. 4
66	5.827000E 00	LARGE ENG, NO. 4
67	3.709000E 00	LARGE ENG, NO. 4
68	3.700900E 00	LARGE ENG, NO. 4
69	3.700900E 00	LARGE ENG, NO. 4
70	5.820000E 00	LARGE ENG, NO. 4
71	5.950000E 00	LARGE ENG, NO. 4
72	3.372000E 00	LARGE ENG, NO. 4
73	3.353000E 00	LARGE ENG, NO. 4
74	3.382000E 00	LARGE ENG, NO. 4
75	6.209800E 00	LARGE ENG, NO. 5
76	6.889000E 00	LARGE ENG, NO. 5
77	8.014000E 00	LARGE ENG, NO. 5
78	8.000000E 00	LARGE ENG, NO. 5
79	3.250000E 00	LARGE ENG, NO. 5
80	3.250000E 00	LARGE ENG, NO. 5
81	4.753000E 00	LARGE ENG, NO. 6
82	5.511800E 00	LARGE ENG, NO. 6
83	7.489300E 00	LARGE ENG, NO. 6
84	7.750000E 00	LARGE ENG, NO. 6
85	7.750000E 00	LARGE ENG, NO. 6
86	4.054000E 00	LARGE ENG, NO. 6
87	4.054000E 00	LARGE ENG, NO. 6
88	4.054000E 00	LARGE ENG, NO. 6
89	2.067000E 00	SMALL ENG, NO. 3
90	2.125000E 00	SMALL ENG, NO. 3
91	2.125900E 00	SMALL ENG, NO. 3
92	2.067000E 00	SMALL ENG, NO. 3

TABLE XXXVII. CALCULATED MAIN SHAFT CARBON SEAL CHARACTERISTICS

MAINSHAFT SEAL CHARACTERISTICS

ROW	SLIP VEL	PV VALUE	PRES.FOR	SP PRESS	FACE PRS	ROW TITLE
1	2.600860E 02	6.501508E 03	9.722647E 00	8.383368E 00	1.338335E 01	SMALL ENG, NO. 2
2	2.600660E 02	1.378330E 04	1.571921E 01	8.393368E 00	1.739334E 01	SMALL ENG, NO. 2
3	1.873381E 02	0.0	0.0	4.237679E 00	4.237679E 00	SMALL ENG, NO. 1
4	4.012301E 02	1.605356E 03	2.375925E-01	4.301478E 00	4.501478E 00	SMALL ENG, NO. 1
5	4.600873E 02	1.706360E 04	1.668735E 01	4.265572E 00	1.633556E 01	SMALL ENG, NO. 1
6	2.638115E 02	3.662173E 03	1.206608E 00	4.265367E 00	4.995366E 00	SMALL ENG, NO. 1
7	1.806160E 02	3.612278E 02	7.900566E-01	4.963632E 00	5.209632E 00	LARGE ENG, NO. 1
8	1.820450E 02	6.735666E 03	1.674966E 01	6.530680E 00	1.146069E 01	LARGE ENG, NO. 1
9	2.054300E 02	1.537327E 04	2.263327E 01	5.975920E 00	1.289192E 01	LARGE ENG, NO. 1
10	2.871445E 02	2.847731E 04	4.106640E 01	6.152725E 00	1.931972E 01	LARGE ENG, NO. 1
11	2.081038E 02	2.802175E 04	4.200004E 01	5.608588E 00	1.820058E 01	LARGE ENG, NO. 1
12	3.274027E 02	2.306046E 04	4.496663E 01	4.675673E 00	1.635567E 01	LARGE ENG, NO. 2
13	1.667863E 02	4.836801E 03	2.052084E 01	2.008358E 00	7.171356E 00	LARGE ENG, NO. 3
14	1.602552E 02	8.012758E 03	3.468312E 01	5.188065E 00	1.268894E 01	LARGE ENG, NO. 3
15	3.667061E 02	1.731030E 04	3.468312E 01	5.188965E 00	1.268894E 01	LARGE ENG, NO. 3
16	2.102084E 02	5.255207E 03	1.150074E 01	7.825567E 00	1.182557E 01	LARGE ENG, NO. 4
17	2.526488E 02	1.616311E 04	2.652010E 01	9.263785E 00	1.950377E 01	LARGE ENG, NO. 4
18	3.135175E 02	1.075128E 04	2.312346E 01	1.046210E 01	2.054208E 01	LARGE ENG, NO. 4
19	3.413345E 02	1.070760E 04	3.674614E 01	4.729598E 00	1.516959E 01	LARGE ENG, NO. 4
20	3.002069E 02	2.475641E 04	4.226703E 01	3.547609E 00	1.639761E 01	LARGE ENG, NO. 4
21	2.357245E 02	1.155050E 04	2.339076E 01	5.027861E 00	1.237784E 01	LARGE ENG, NO. 5
22	2.181666E 02	1.418082E 04	3.214209E 01	6.700598E 00	1.771059E 01	LARGE ENG, NO. 5
23	3.113403E 02	2.153712E 04	3.214209E 01	6.700598E 00	1.771059E 01	LARGE ENG, NO. 5
24	3.580066E 02	1.754232E 04	2.370161E 01	6.284801E 00	1.373280E 01	LARGE ENG, NO. 5
25	4.325081E 02	4.325081E 04	8.972379E 01	5.656230E 00	2.315620E 01	LARGE ENG, NO. 5
26	4.325081E 02	4.325081E 04	8.972398E 01	5.656230E 00	2.315620E 01	LARGE ENG, NO. 5
27	2.378873E 02	3.021148E 03	7.200002E 00	3.568509E 00	5.707598E 00	LARGE ENG, NO. 6
28	2.263066E 02	6.608148E 03	1.470763E 01	4.414058E 00	8.704056E 00	LARGE ENG, NO. 6
29	2.263066E 02	1.643834E 04	3.078662E 01	5.377687E 00	1.494768E 01	LARGE ENG, NO. 6
30	2.068011E 02	1.881405E 04	3.078662E 01	5.253369E 00	1.482334E 01	LARGE ENG, NO. 6
31	4.077793E 02	2.103852E 04	3.580040E 01	4.181179E 00	1.225119E 01	LARGE ENG, NO. 6
32	4.327761E 02	2.475470E 04	6.076173E 01	6.326082E 00	1.776607E 01	LARGE ENG, NO. 6
33	2.778445E 02	1.333654E 04	3.222987E 01	4.367511E 00	1.252751E 01	LARGE ENG, NO. 6

TABLE XXXVIII. CALCULATED RING SEAL CHARACTERISTICS

RING SEAL CHARACTERISTICS

ROW	RUB VEL	PV VALUE	AC AREA	AO AREA	PRESS. FORCE BACK-TO-BACK	ROW TITLE
1	2.498279E 02	5.666383E 03	2.896067E-01	4.079141E-02	0.0	SMALL ENG, NO. 2
2	1.705761E 02	1.699693E 04	7.390543E-01	3.828835E-01	0.0	LARGE ENG, NO. 1
3	1.757048E 02	1.282645E 04	5.048259E-01	1.952340E-01	0.0	LARGE ENG, NO. 2
4	1.753600E 02	2.279673E 03	5.452097E-01	1.449969E-01	0.0	LARGE ENG, NO. 2
5	1.753600E 02	2.279679E 03	5.452097E-01	1.449969E-01	2.714411E 00	LARGE ENG, NO. 2
6	1.313712E 02	2.496052E 03	1.314416E 00	7.916770E-01	0.0	LARGE ENG, NO. 3
7	2.254237E 02	9.242371E 03	5.904741E-01	3.133512E-01	0.0	LARGE ENG, NO. 4
8	1.541329E 02	3.133728E 03	3.928747E-01	5.862444E-01	5.097431E 00	LARGE ENG, NO. 4
9	2.091598E 02	1.024883E 04	6.023964E-01	5.323626E-01	2.042210E 01	LARGE ENG, NO. 5

ROW	NET FORCE BACK-TO-BACK	PRESS. FORCE TRIPLE	NET FORCE TRIPLE	NET FORCE SINGLE	FACE WIDTH	ROW TITLE
1	0.0	0.0	0.0	4.317499E 00	2.400017E-02	SMALL ENG, NO. 2
2	0.0	2.432954E 01	5.432954E 01	0.0	4.999979E-02	LARGE ENG, NO. 1
3	0.0	1.099274E 01	2.039273E 01	0.0	4.199982E-02	LARGE ENG, NO. 2
4	0.0	0.0	0.0	5.429923E 00	3.800011E-02	LARGE ENG, NO. 2
5	8.714411E 00	0.0	0.0	0.0	3.800011E-02	LARGE ENG, NO. 2
6	0.0	0.0	0.0	2.752881E 01	5.200005E-02	LARGE ENG, NO. 3
7	0.0	9.317370E 00	2.031737E 01	0.0	4.600000E-02	LARGE ENG, NO. 4
8	1.258743E 01	0.0	0.0	0.0	3.500032E-02	LARGE ENG, NO. 4
9	3.842210E 01	0.0	0.0	0.0	3.200006E-02	LARGE ENG, NO. 5

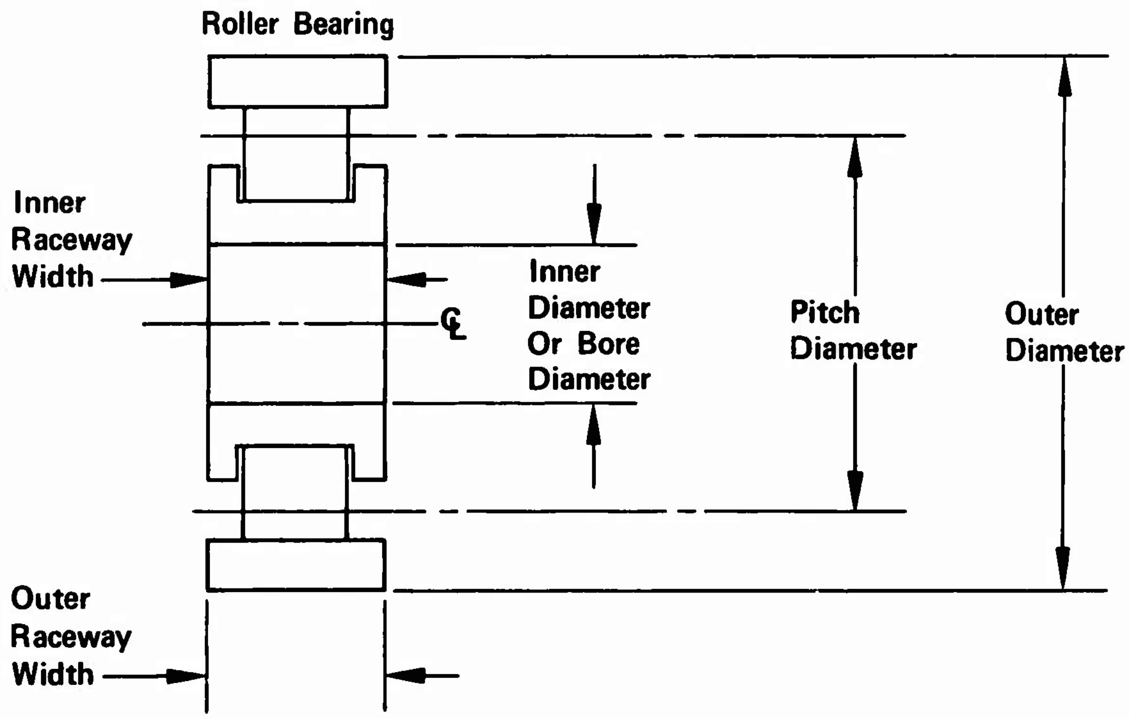

Figure 1. External Roller Bearing Geometry.

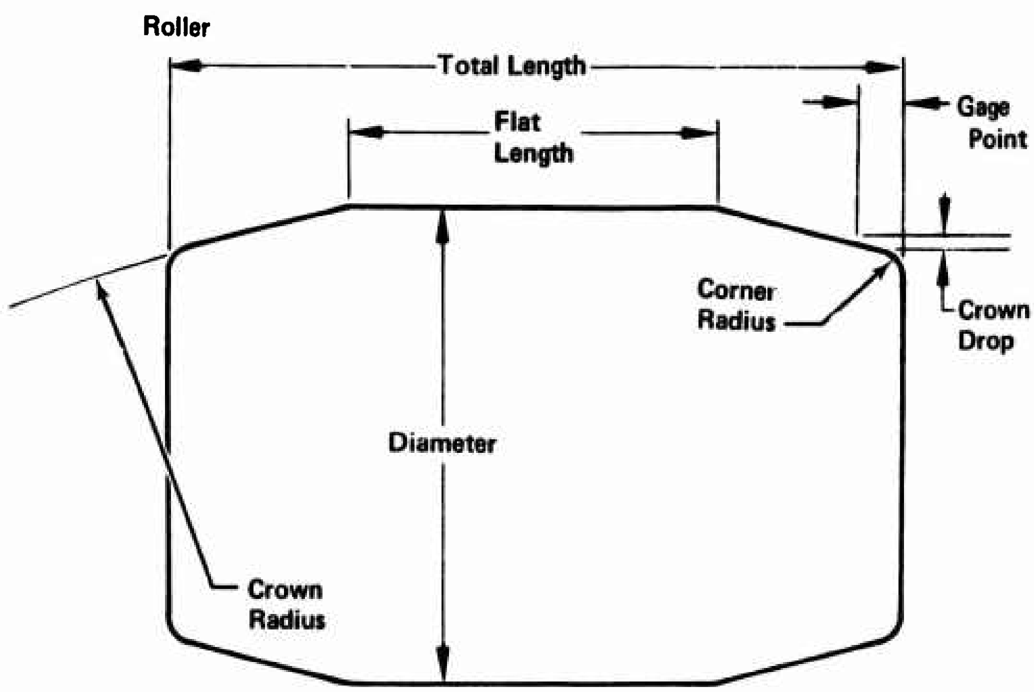

Figure 2. Roller Element Geometry.

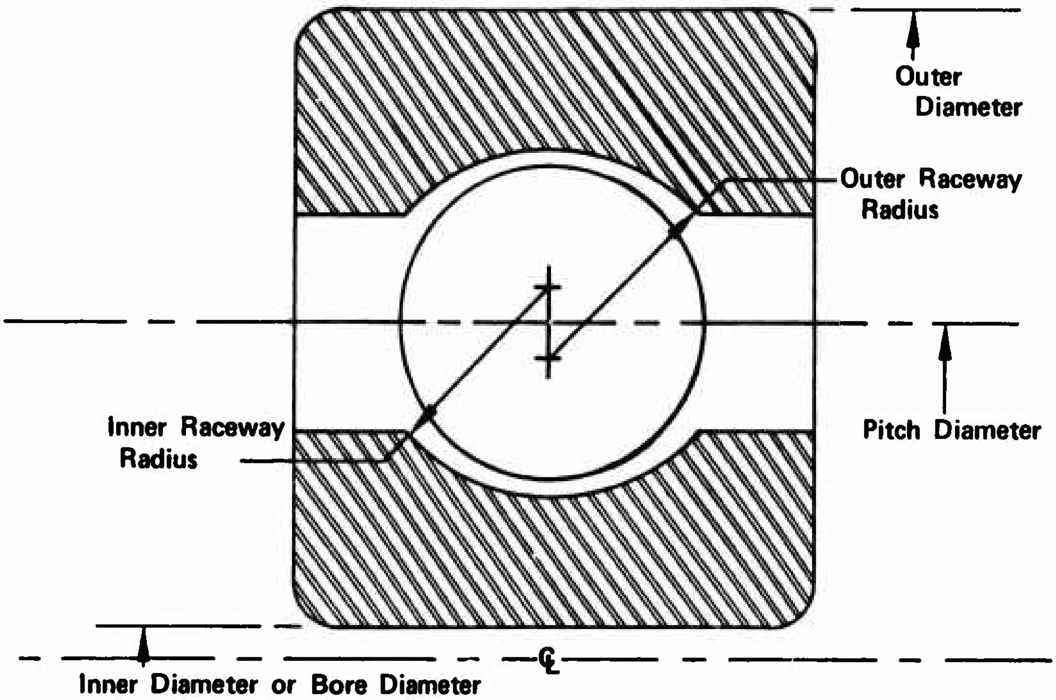

Figure 3. Ball Bearing Geometry.

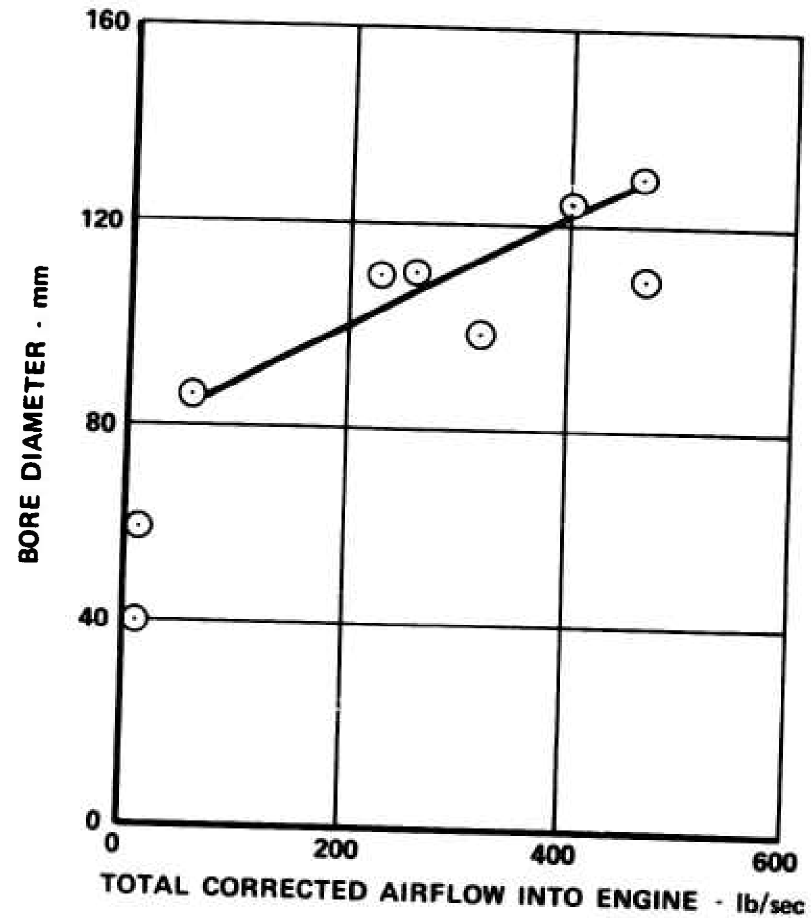

Figure 4. Low Rotor Ball Bearings at Sea Level Takeoff; Bore Diameter vs Total Corrected Airflow Into Engine.

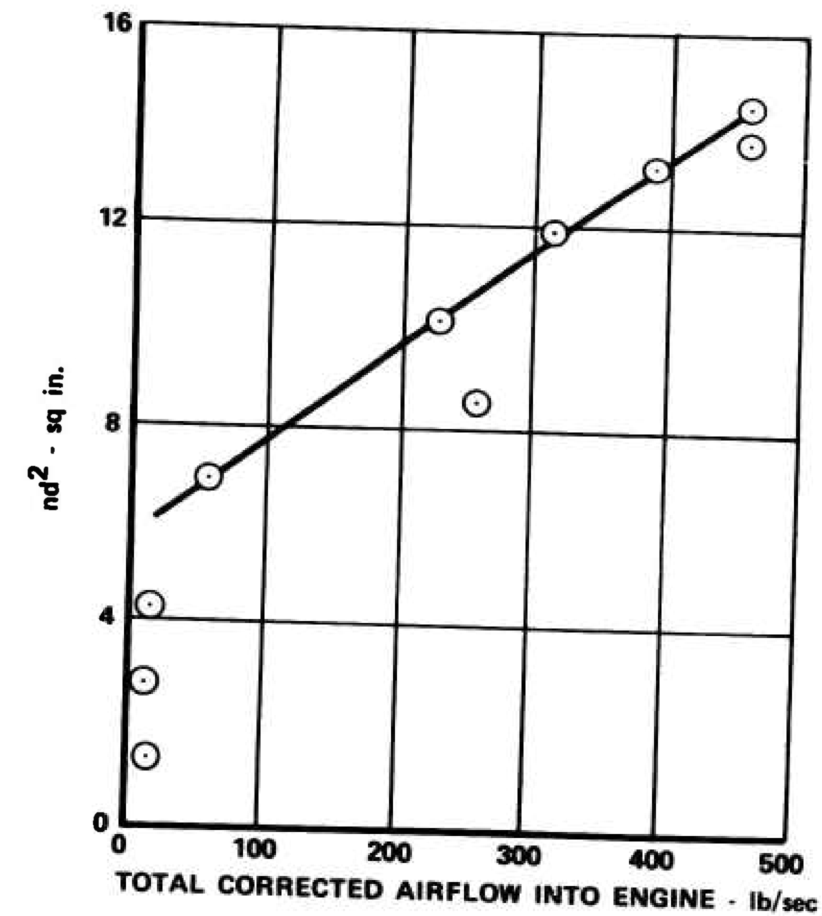

Figure 5. Low Rotor Ball Bearings at Sea Level Takeoff; nd^2 vs Total Corrected Airflow Into Engine.

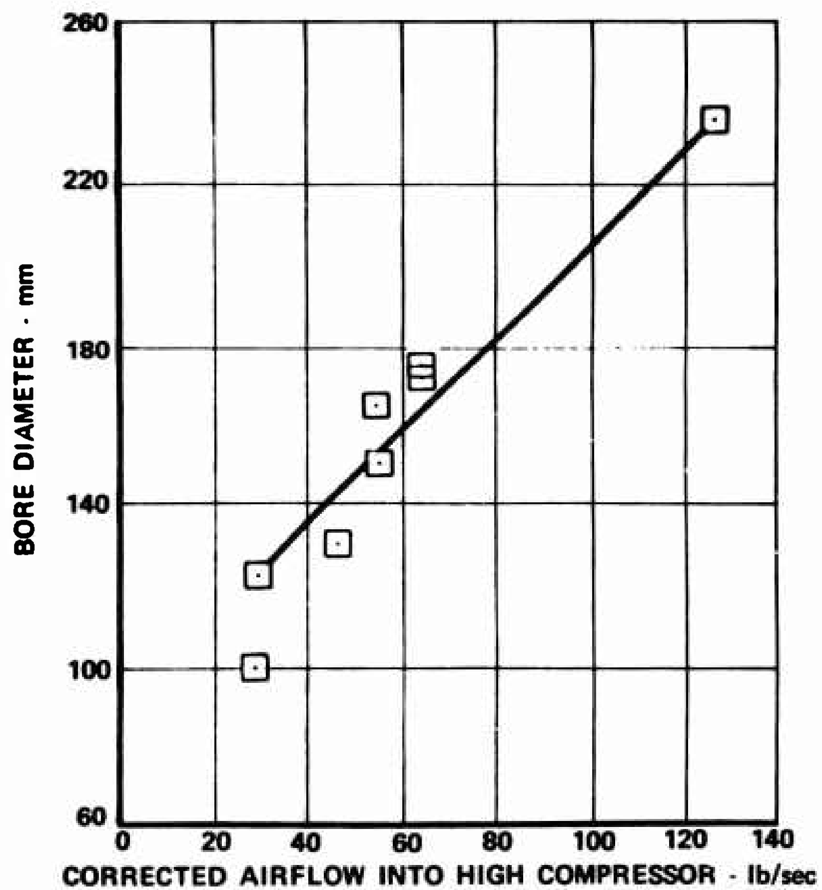

Figure 6. High Rotor Roller Bearings at Sea Level Takeoff; Bearing Bore Diameter vs Corrected Airflow Into High Compressor.

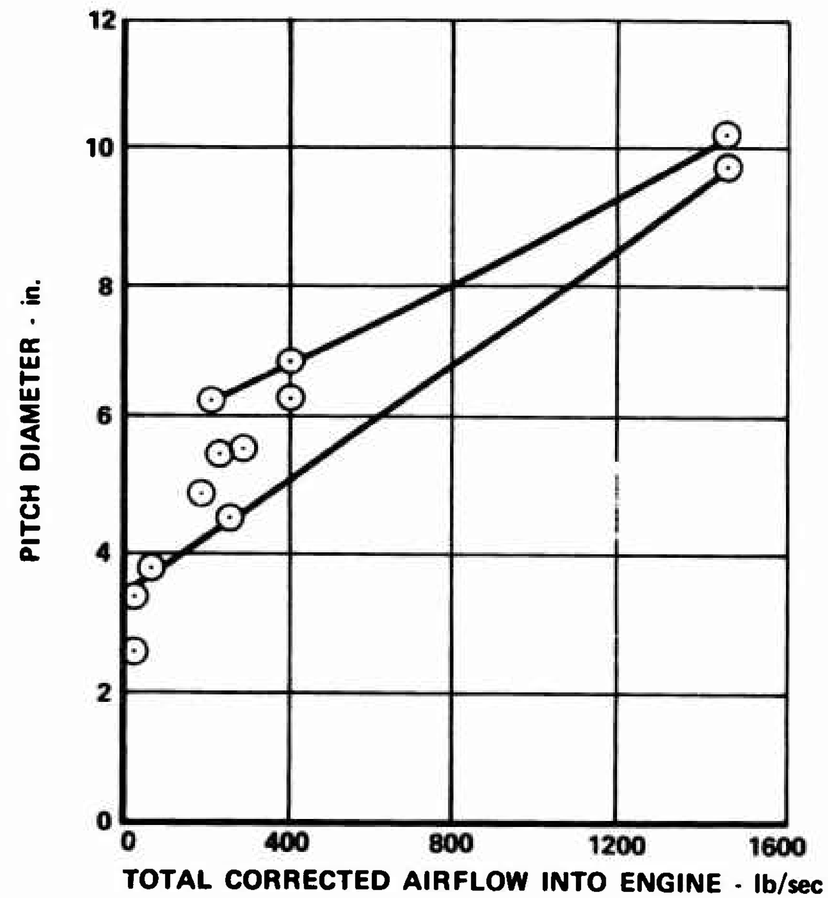

Figure 7. Low Rotor Seals at Sea Level Takeoff; Seal Pitch Diameter vs Total Corrected Airflow Into Engine.

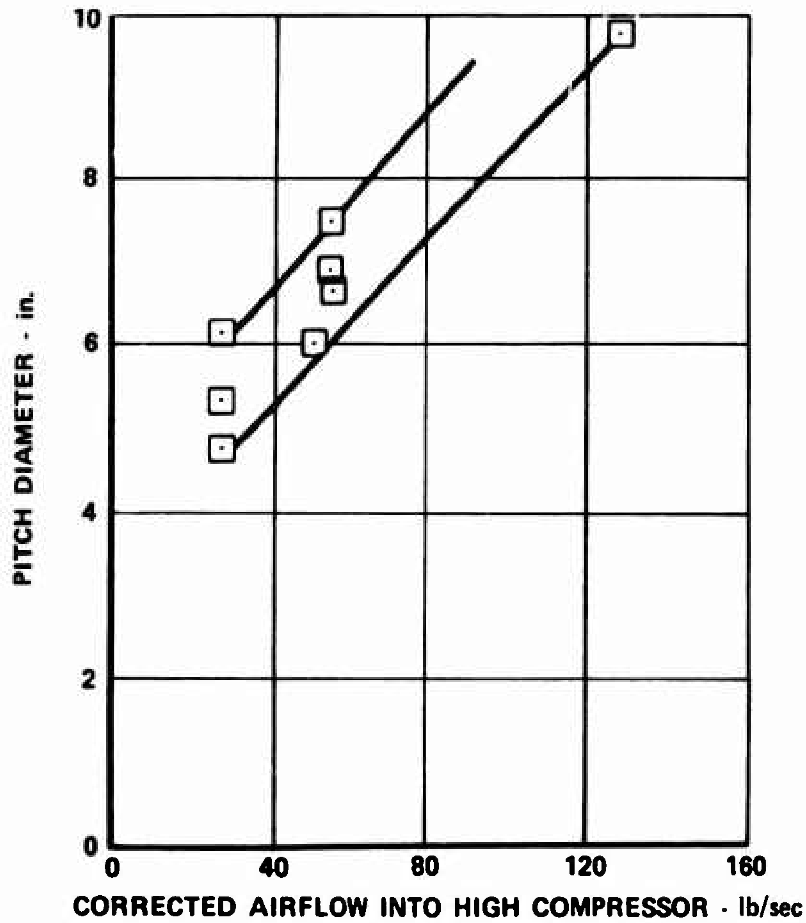

Figure 8. High Rotor Seals at Sea Level Takeoff; Seal Pitch Diameter vs Corrected Airflow Into High Compressor.

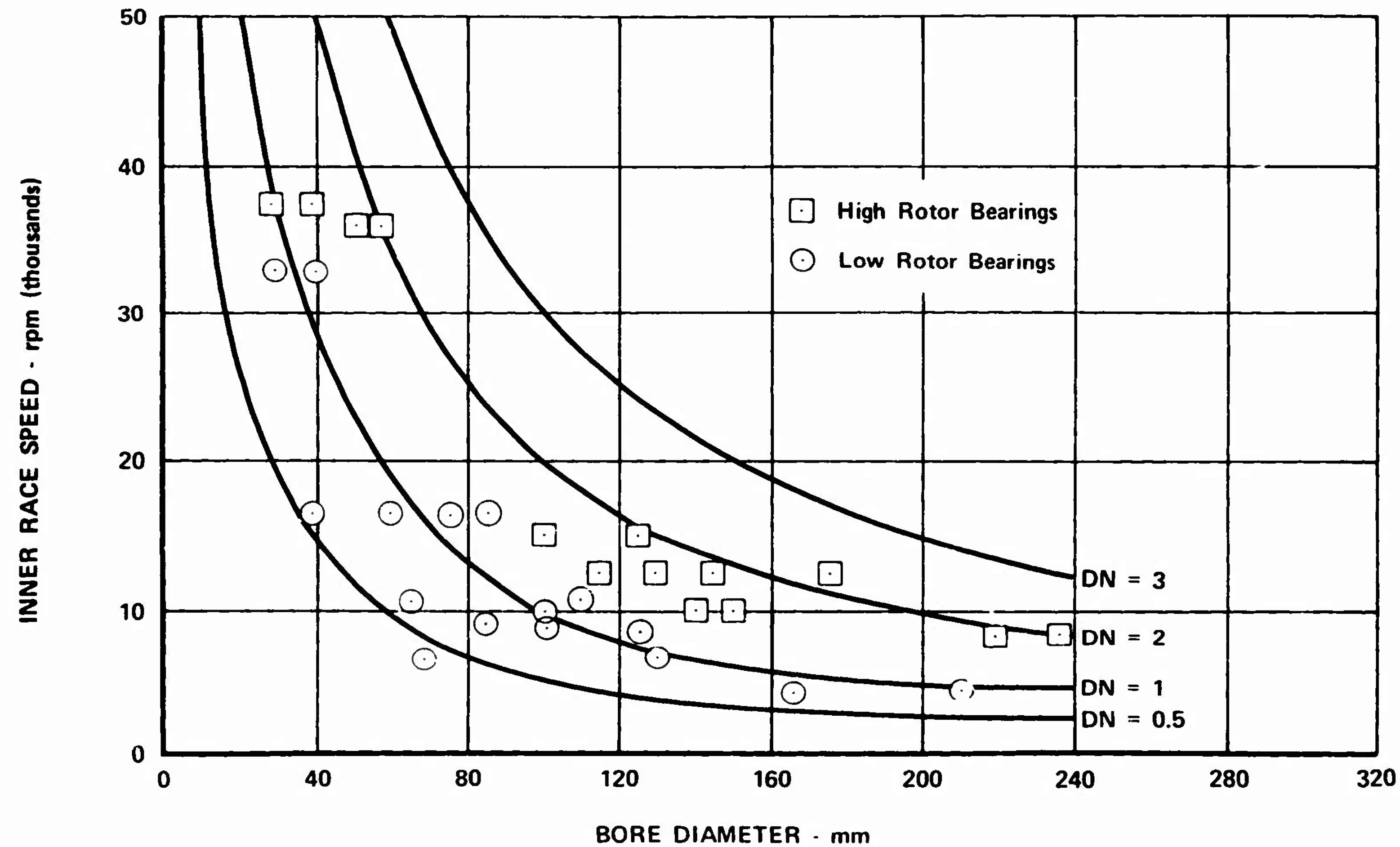

Figure 9. High and Low Rotor Bearings at Sea Level Takeoff; Inner Race Speed vs Bore Diameter.

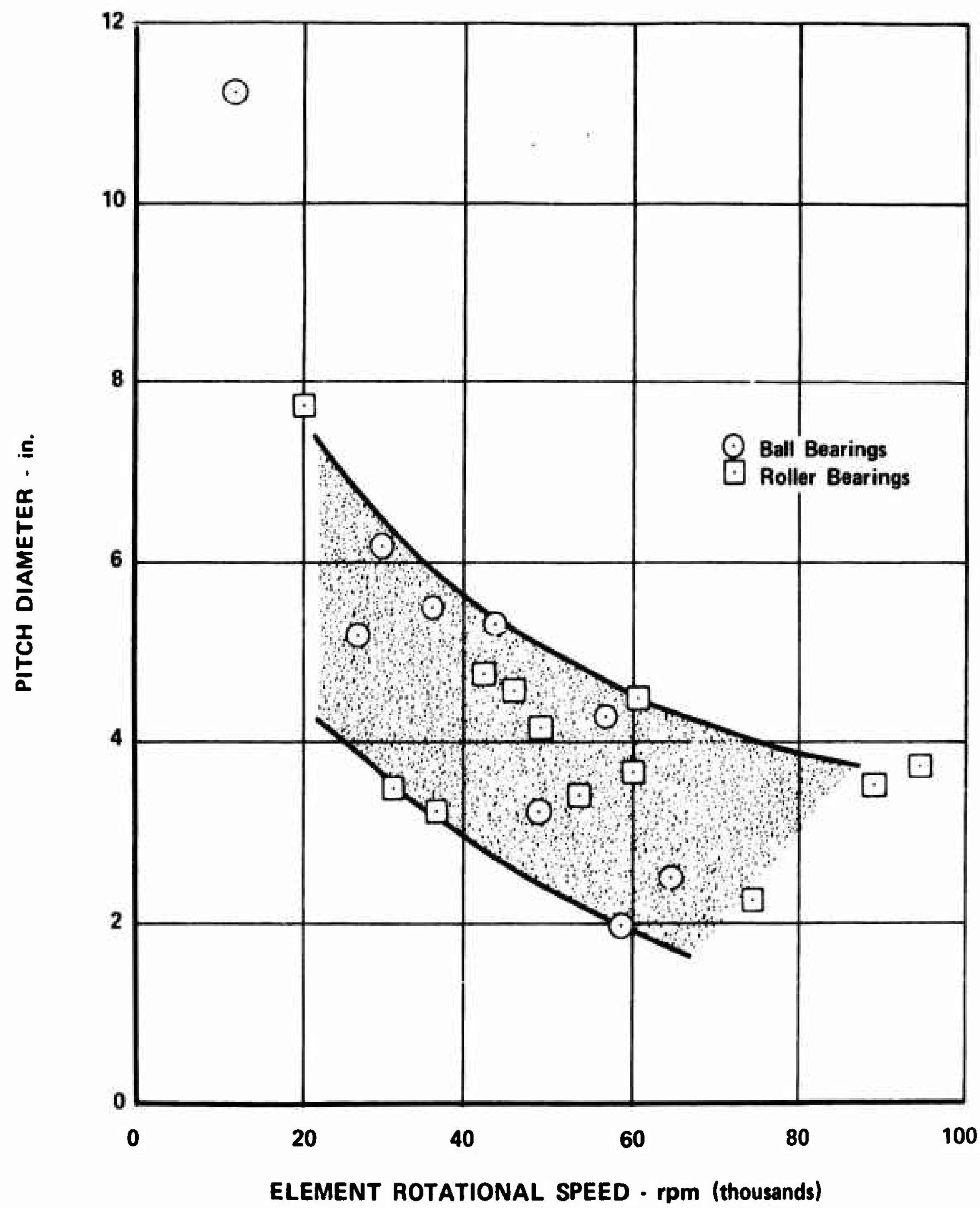

Figure 10. Low Rotor Bearings at Sea Level Takeoff; Pitch Diameter vs Element Rotational Speed.

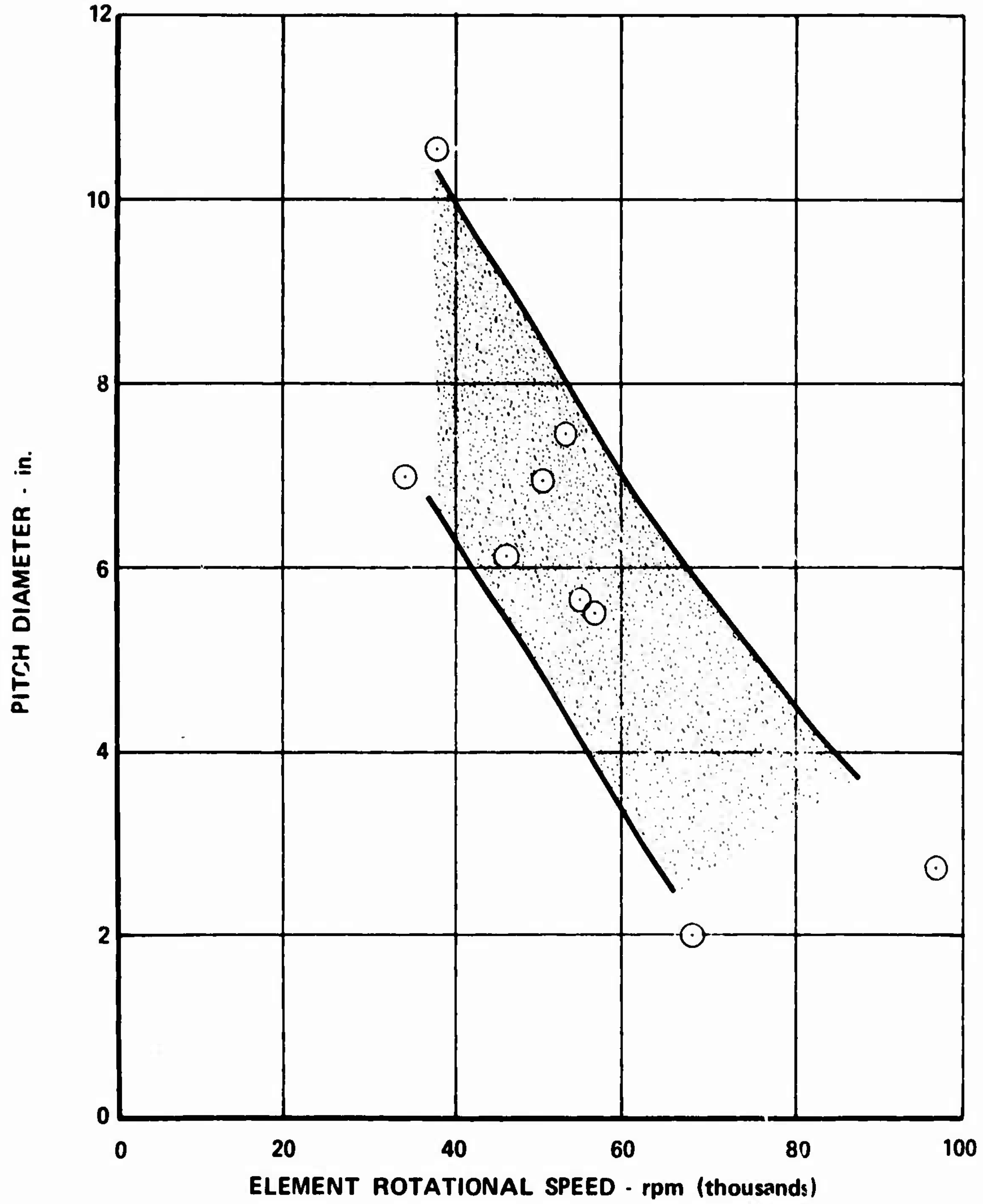

Figure 11. High Rotor Ball Bearings at Sea Level Takeoff; Pitch Diameter vs Element Rotational Speed.

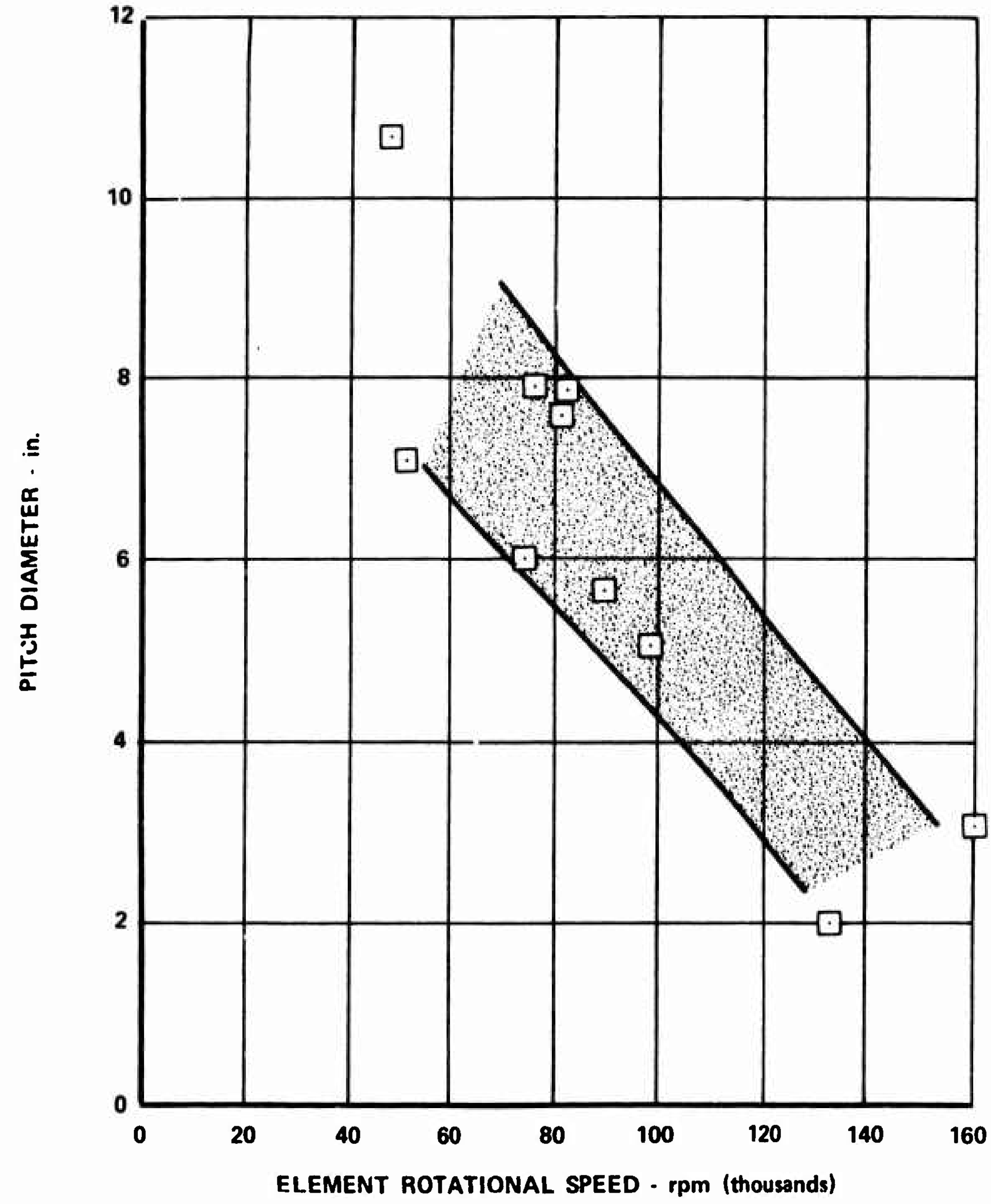

Figure 12. High Rotor Roller Bearings at Sea Level Takeoff; Pitch Diameter vs Element Rotational Speed.

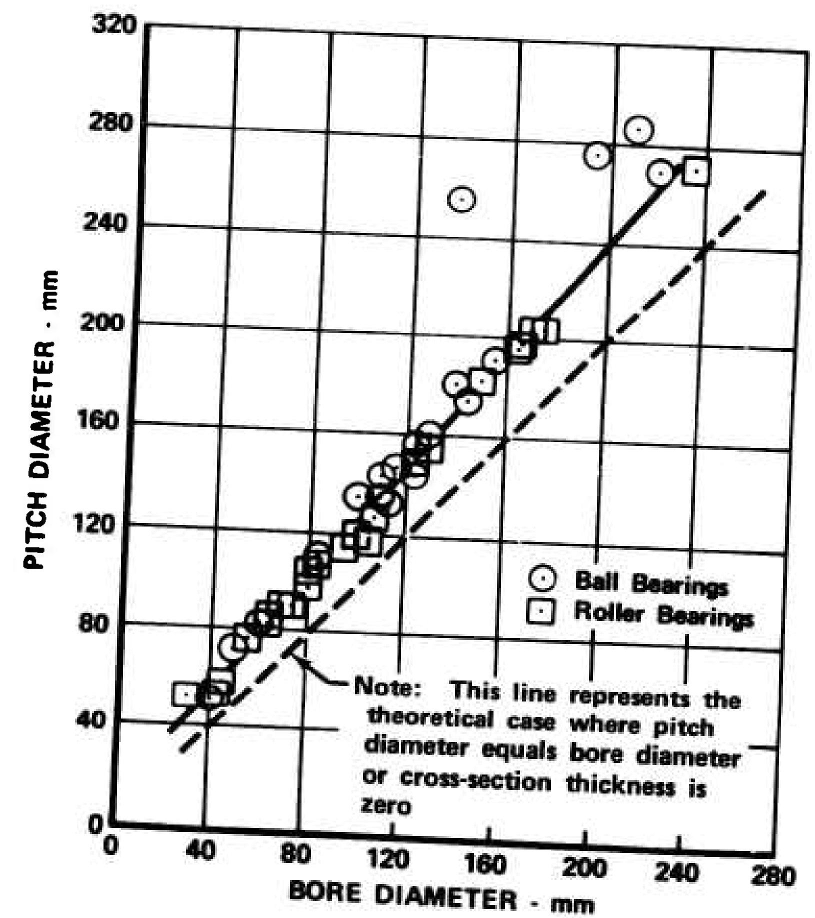

Figure 13. High and Low Rotor Bearings; Pitch Diameter vs Bore Diameter.

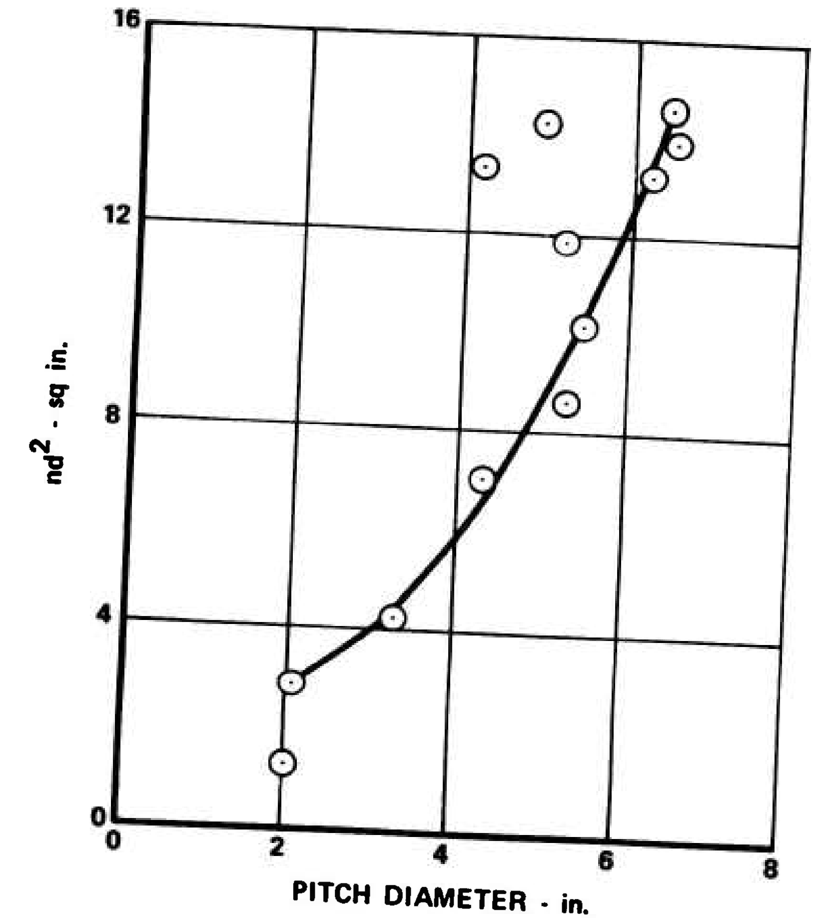

Figure 14. Low Rotor Ball Bearings; nd^2 vs Pitch Diameter.

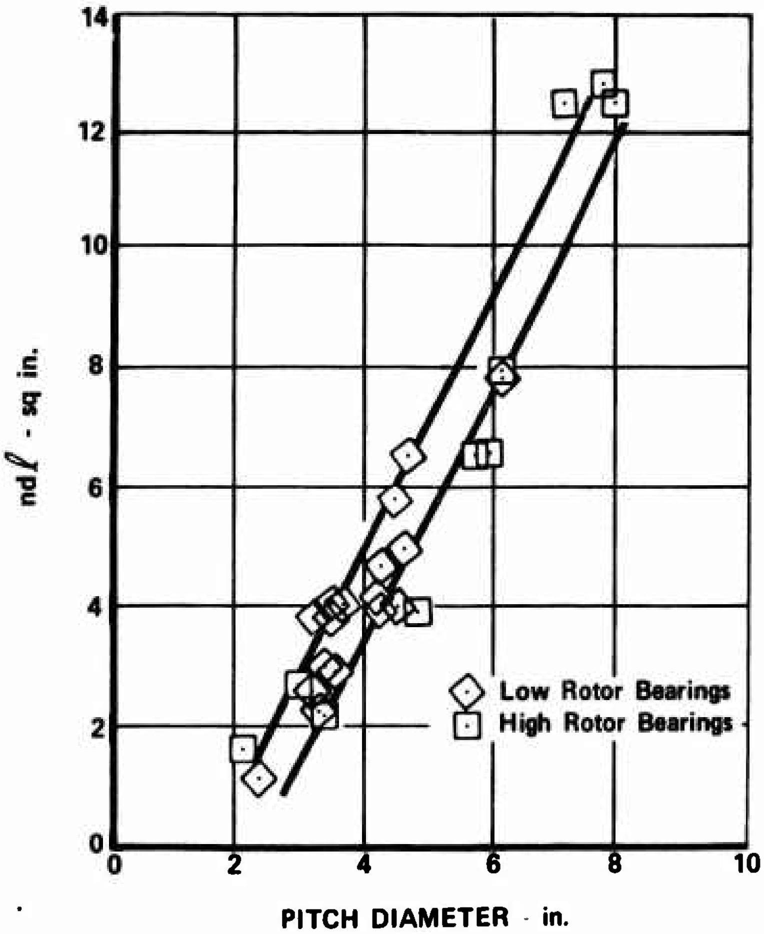

Figure 15. High and Low Rotor Roller Bearings; ndℓ vs Pitch Diameter.

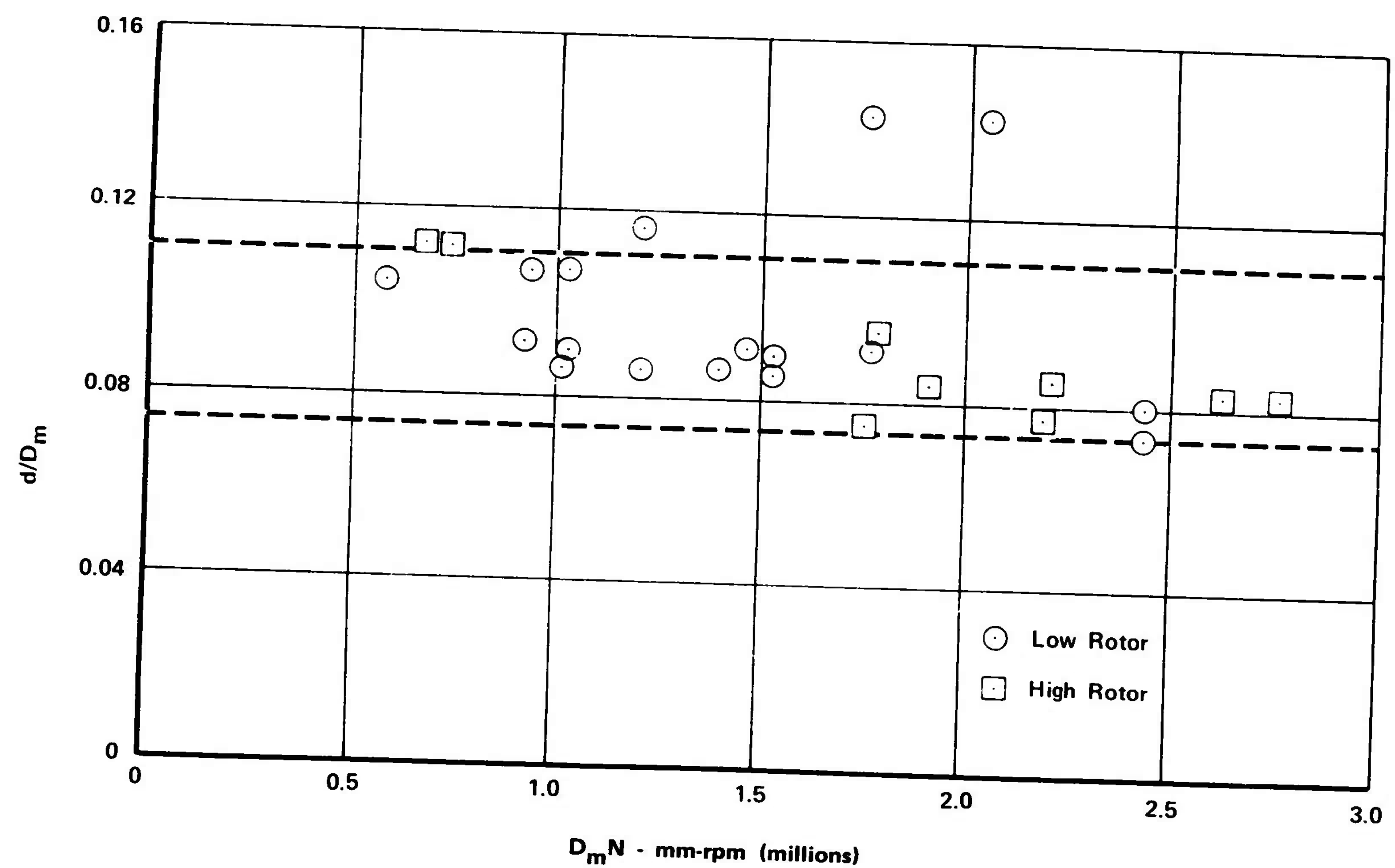

Figure 16. High and Low Rotor Roller Bearings at Sea Level Takeoff; Roller Diameter/Pitch Diameter vs Product of Pitch Diameter and Shaft Speed.

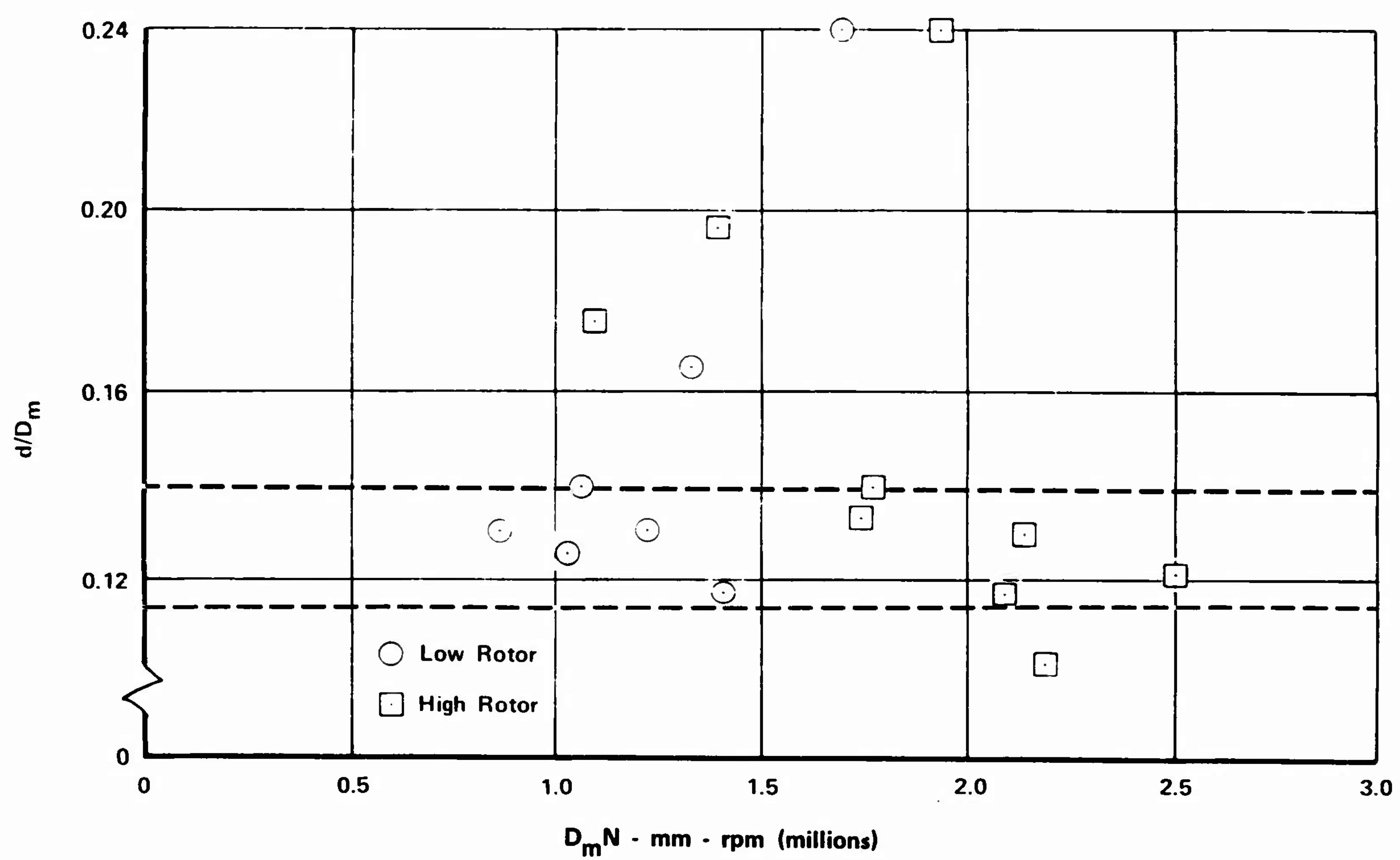

Figure 17. High and Low Rotor Ball Bearings at Sea Level Takeoff; Ball Diameter/Pitch Diameter vs Product of Pitch Diameter and Shaft Speed.

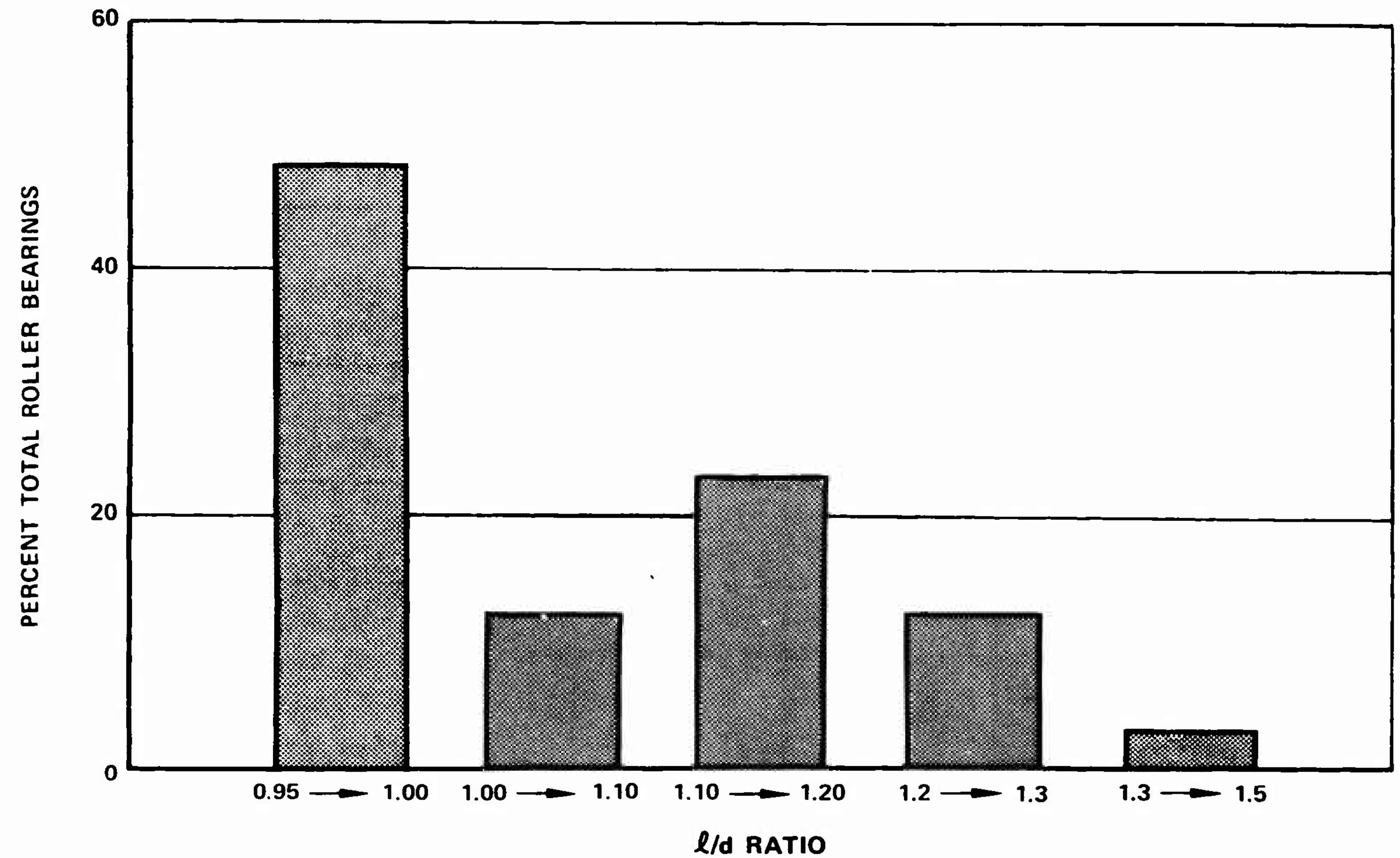

Figure 18. High and Low Rotor Roller Bearings; Percent Total Roller Bearings vs L/D Ratio.

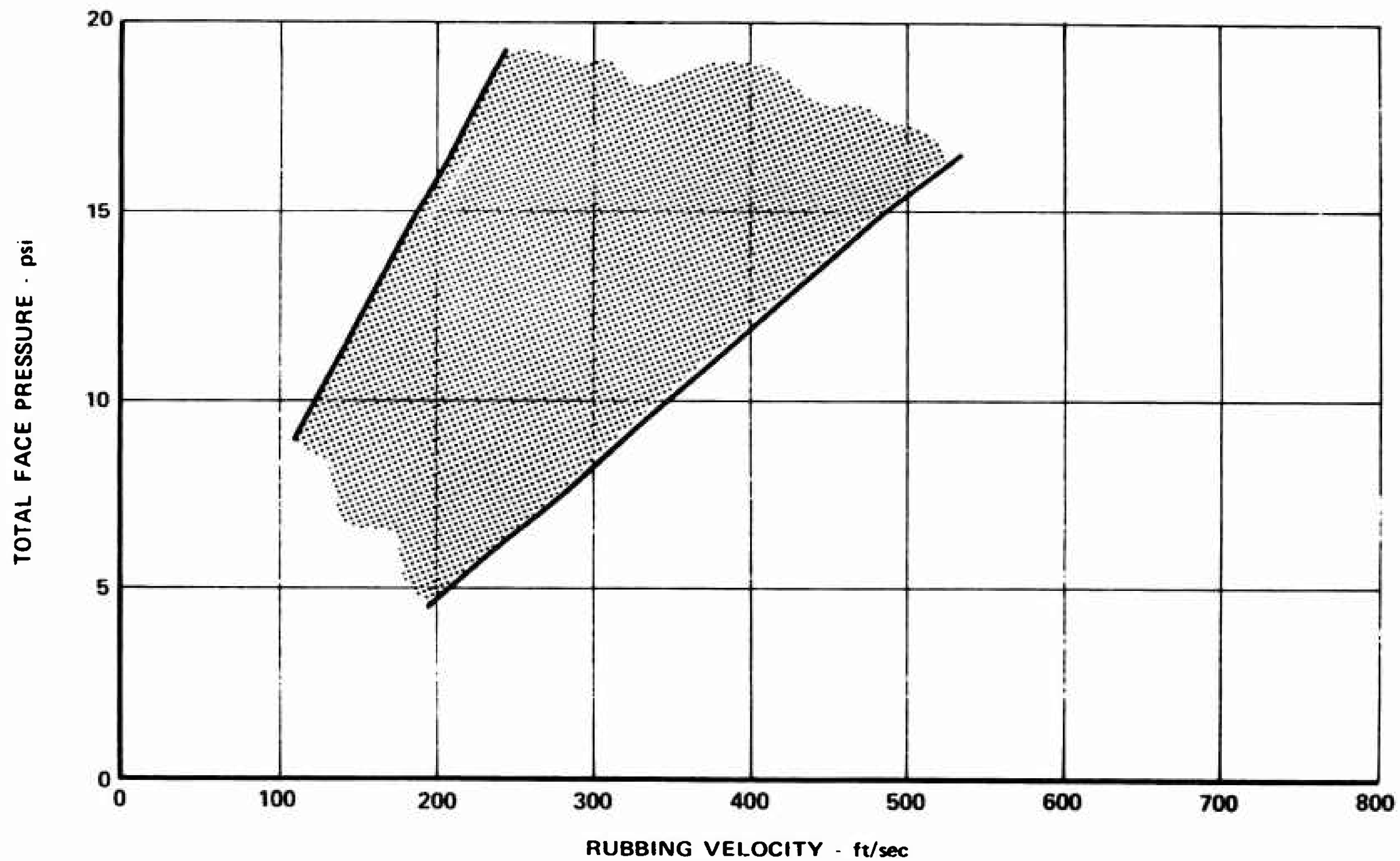

Figure 19. High and Low Rotor Seals at Sea Level Takeoff; Total Face Pressure vs Rubbing Velocity.

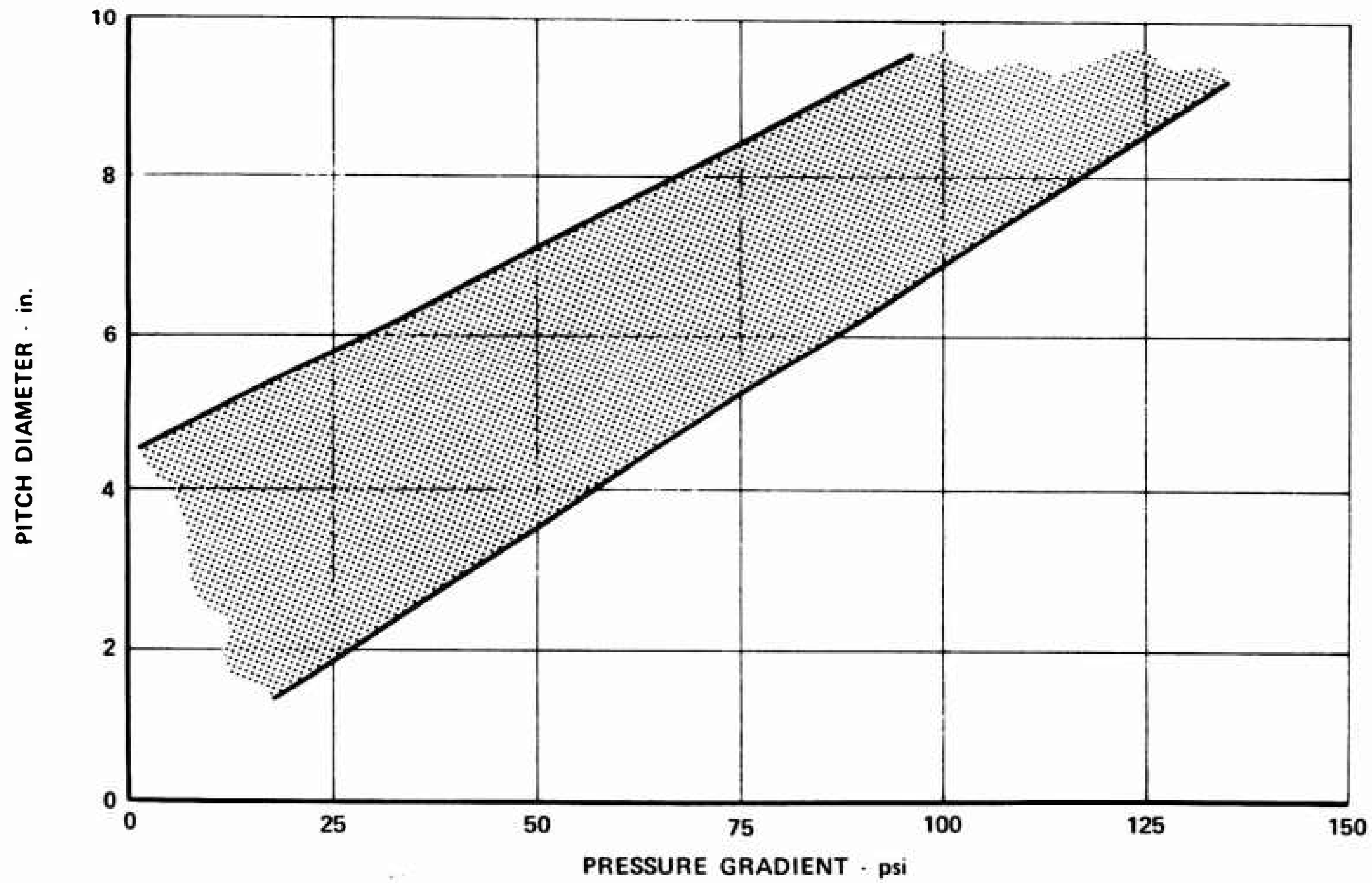

Figure 20. High and Low Rotor Seals at Sea Level Takeoff; Pitch Diameter vs Pressure Gradient.

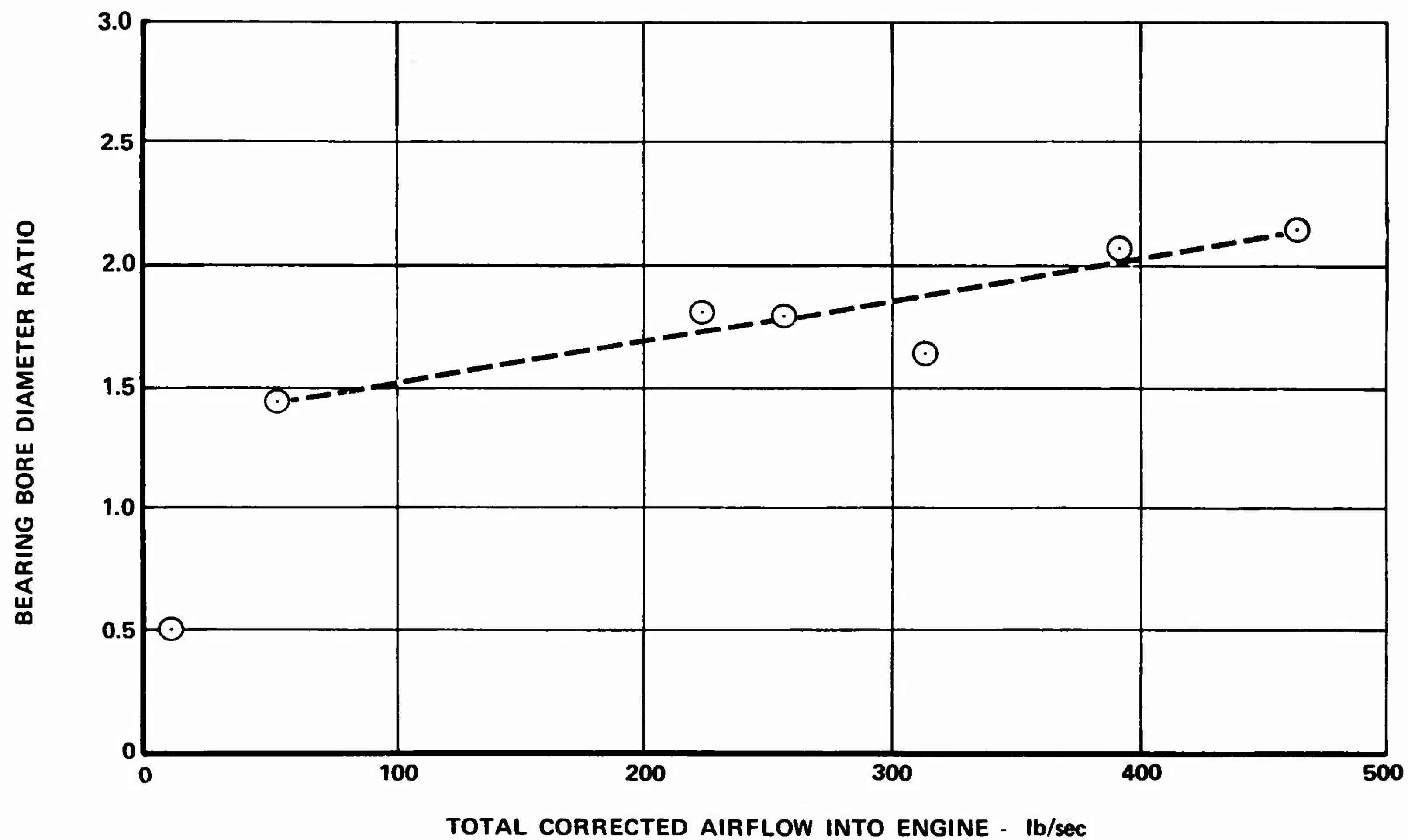

Figure 21. Low Rotor Ball Bearings at Sea Level Takeoff; Bearing Bore Diameter Ratio vs Total Corrected Airflow Into Engine.

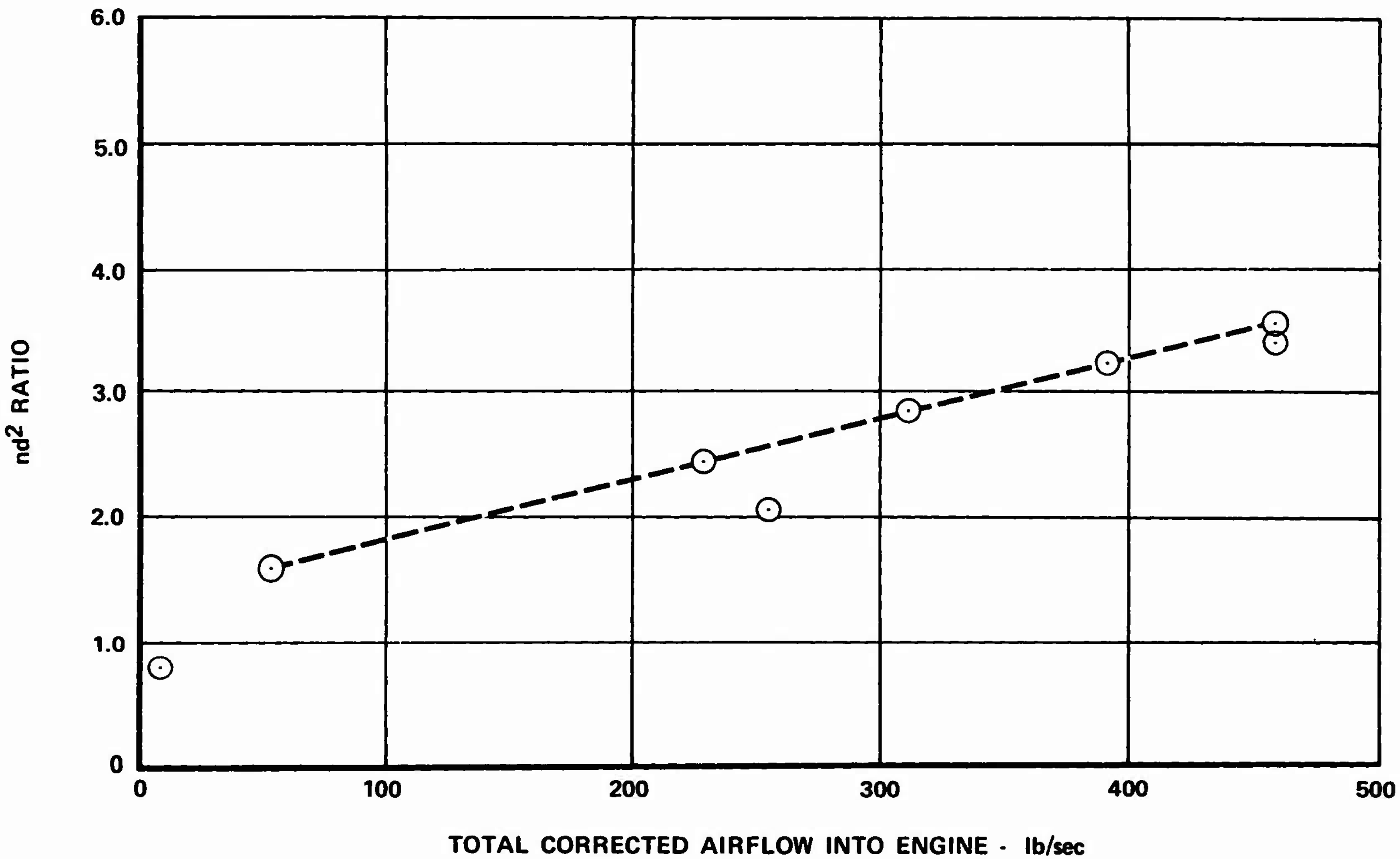

Figure 22. Low Rotor Ball Bearings at Sea Level Takeoff; nd^2 Ratio vs Total Corrected Airflow Into Engine.

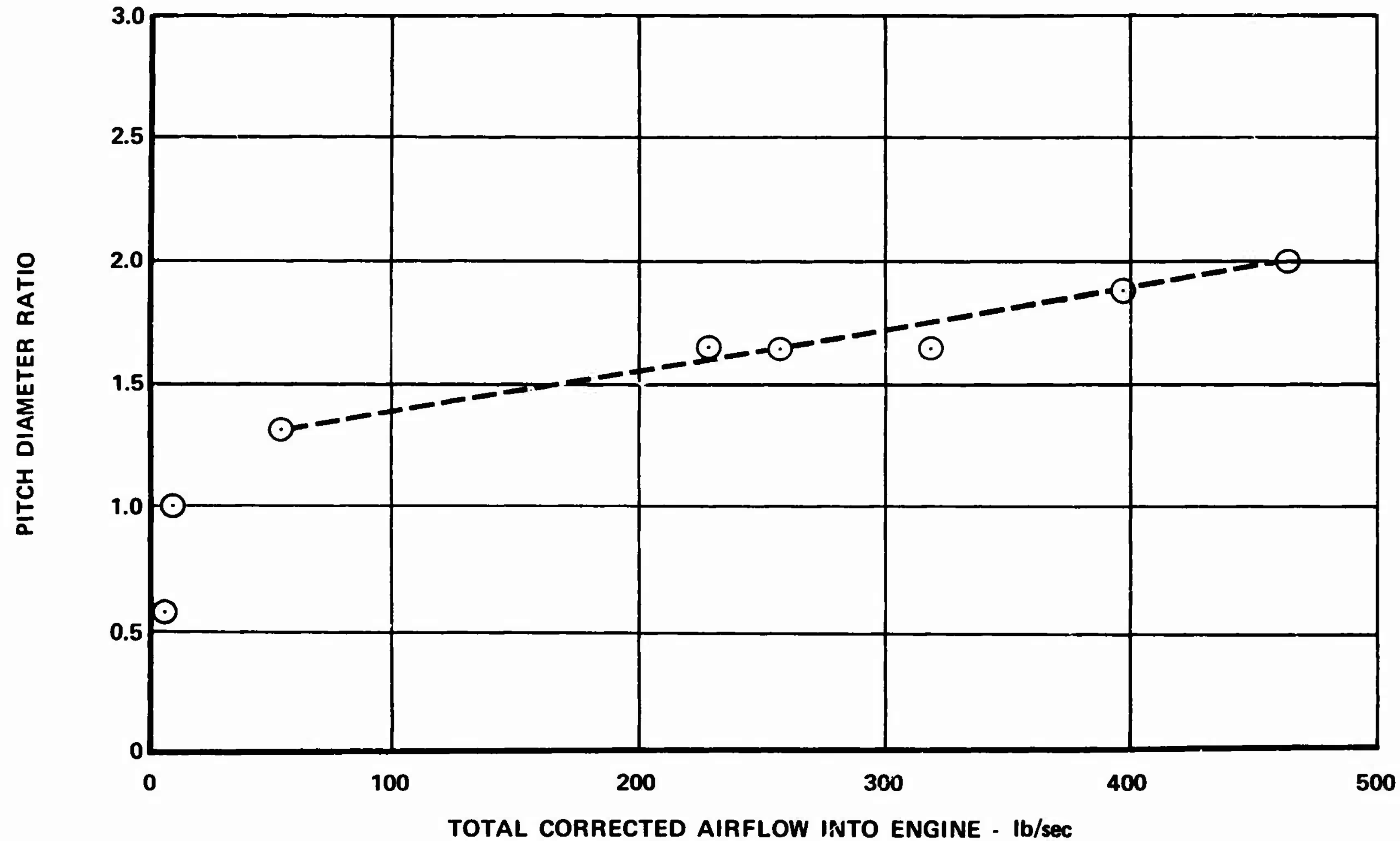

Figure 23. Low Rotor Ball Bearings at Sea Level Takeoff; Pitch Diameter Ratio vs Total Corrected Airflow Into Engine.

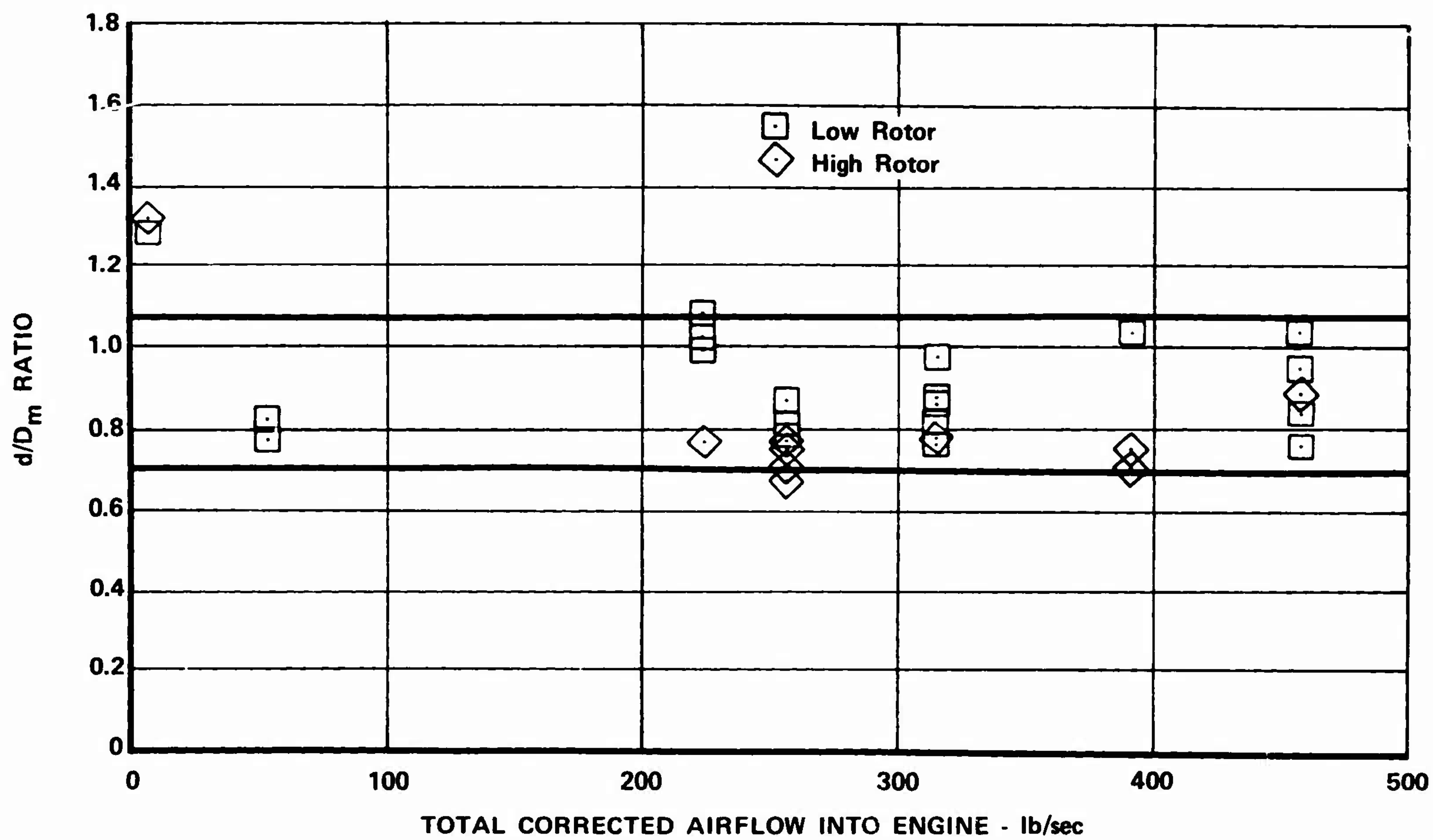

Figure 24. High and Low Rotor Roller Bearings at Sea Level Takeoff; d/D_m Ratio vs Total Corrected Airflow Into Engine.

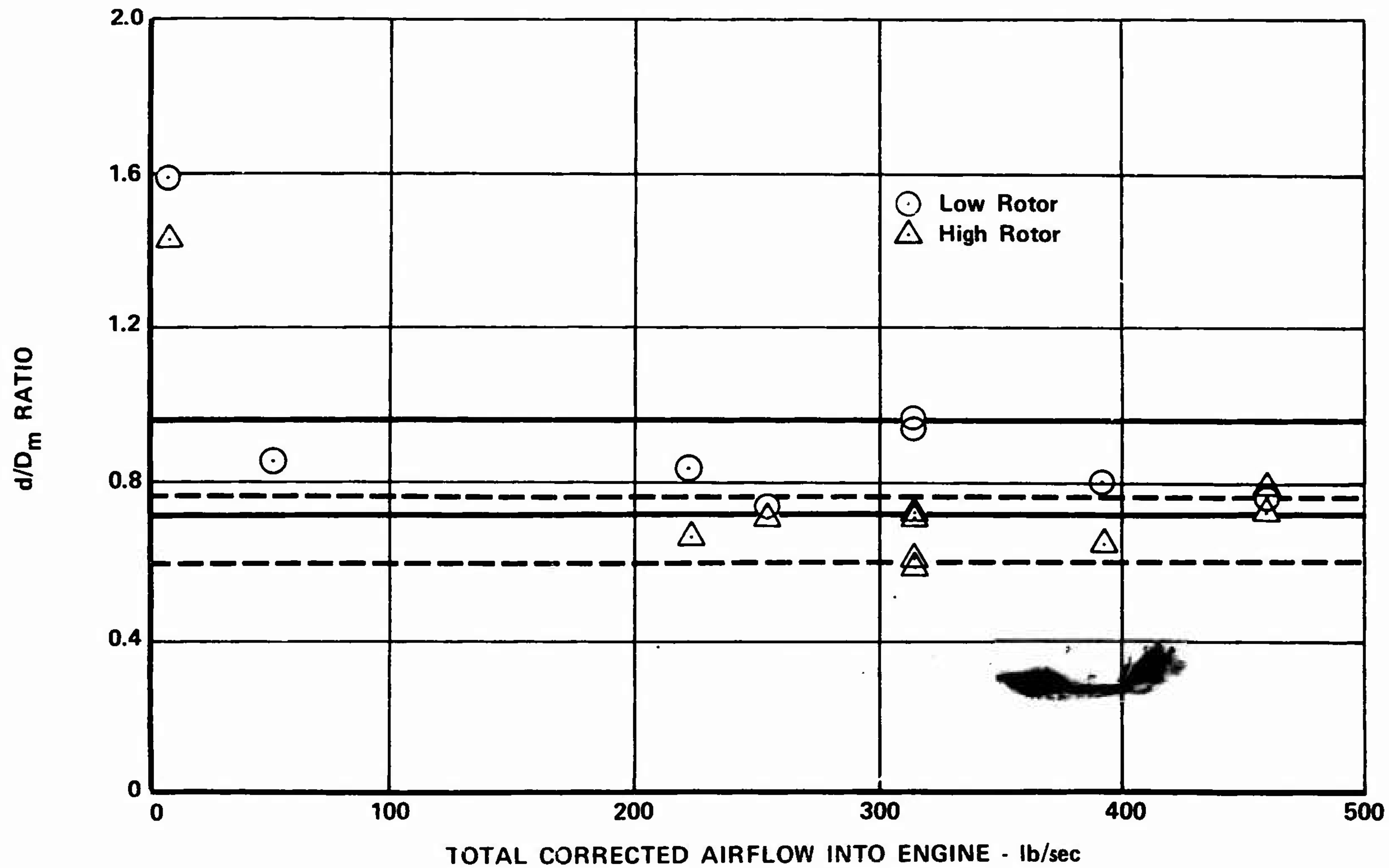

Figure 25. High and Low Rotor Ball Bearings at Sea Level Takeoff; d/D_m Ratio vs Total Corrected Airflow Into Engine.

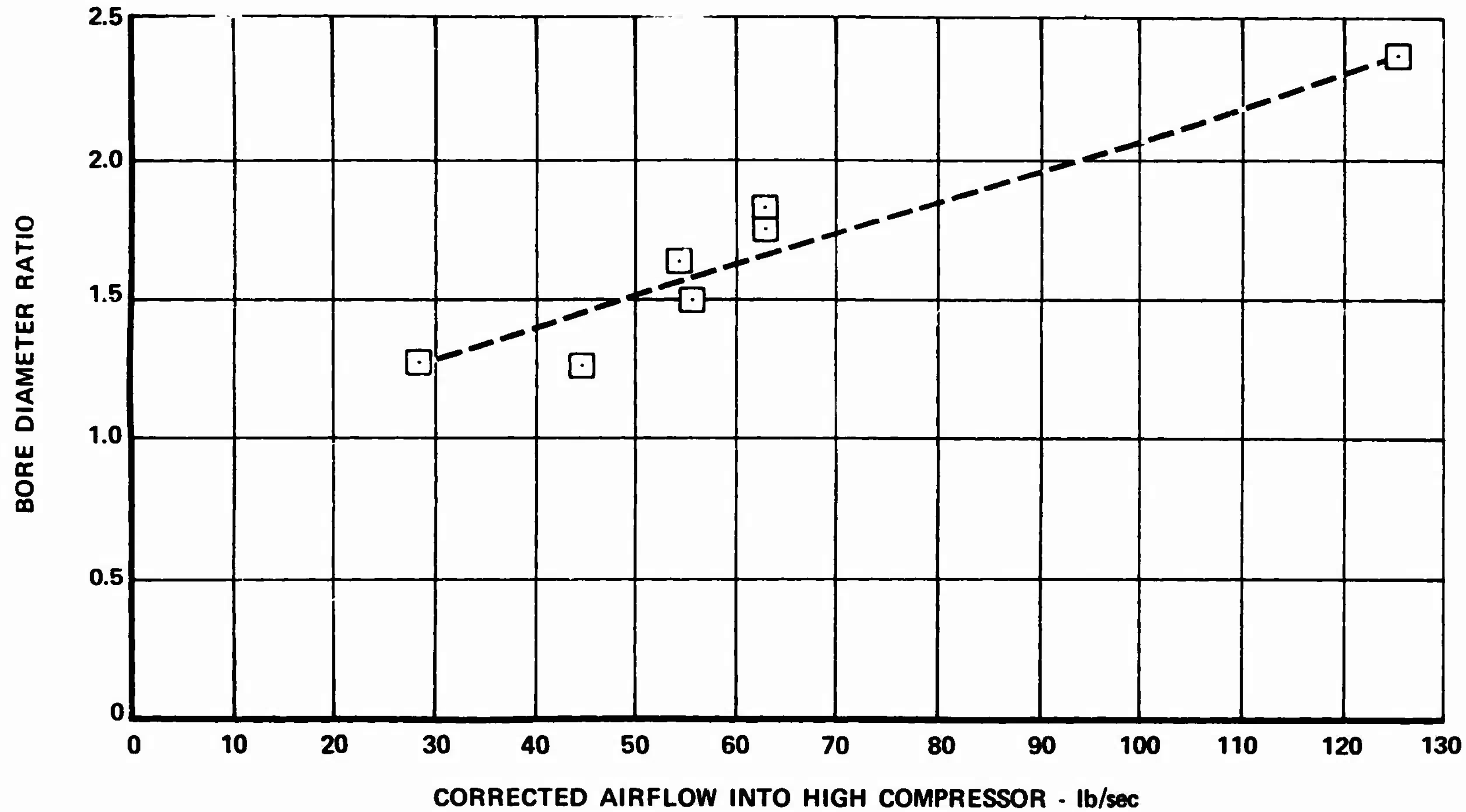

Figure 26. High Rotor Roller Bearings at Sea Level Takeoff; Bore Diameter Ratio vs Corrected Airflow Into High Compressor.

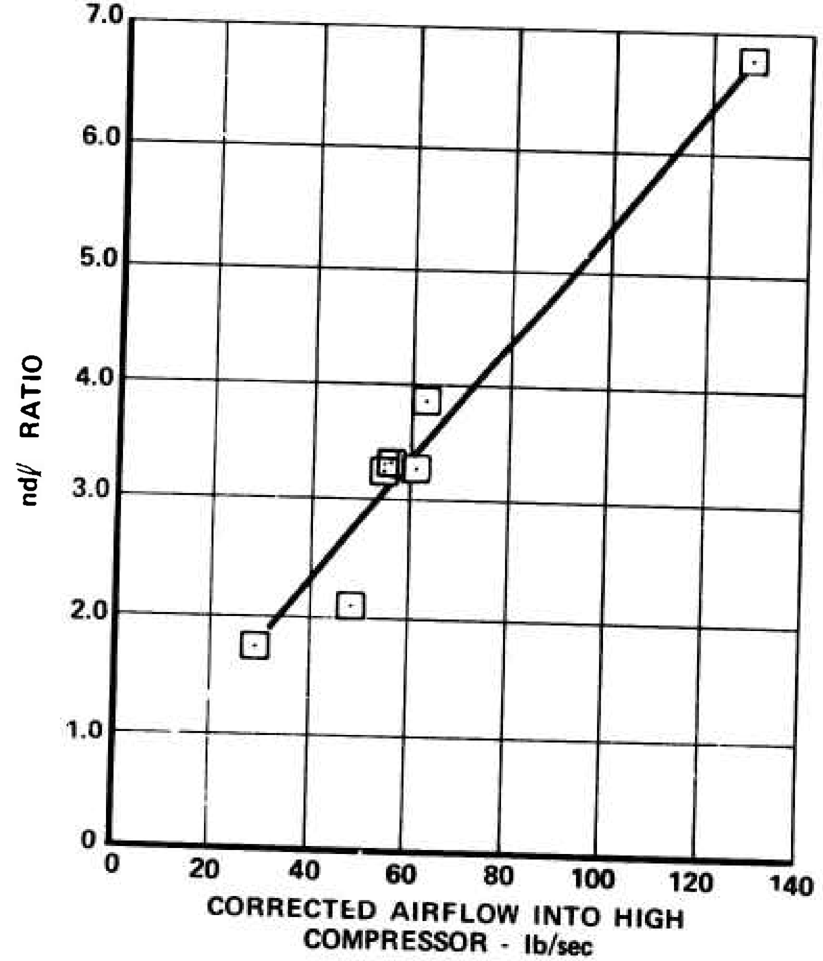

Figure 27. High Rotor Roller Bearings at [illegible]el Takeoff; ndℓ Ratio vs Corrected [illegible]low Into High Compressor.

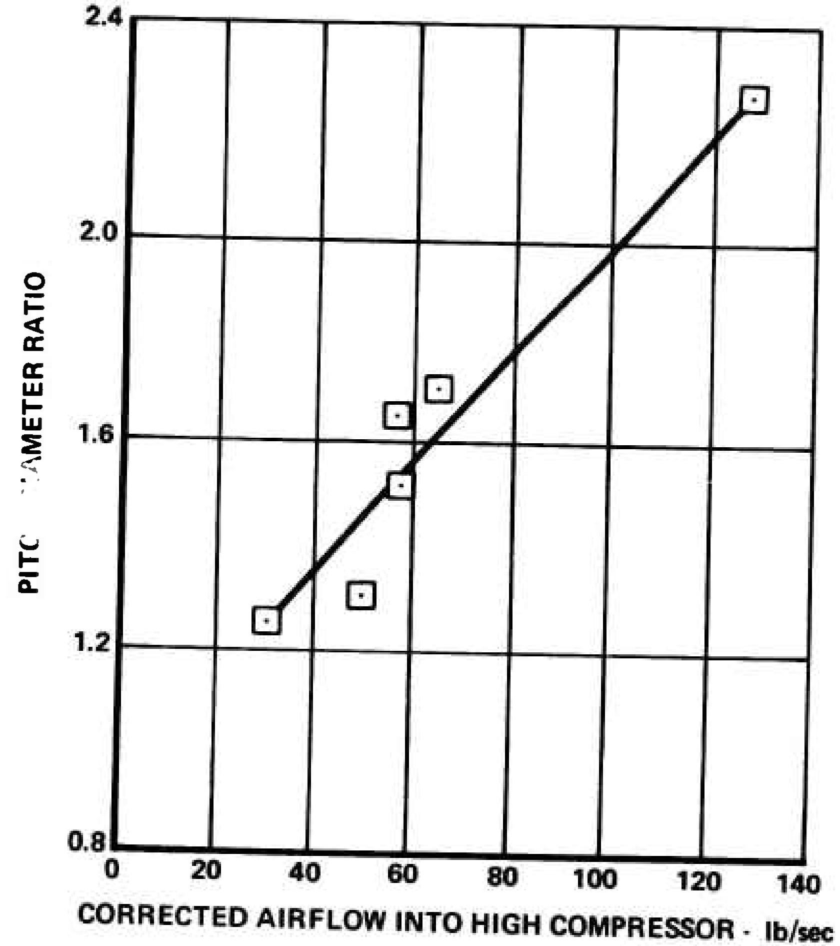

Figure 28. High Rotor Roller Bearings at Sea Level Takeoff; Pitch Diameter Ratio vs Corrected Airflow Into High Compressor.

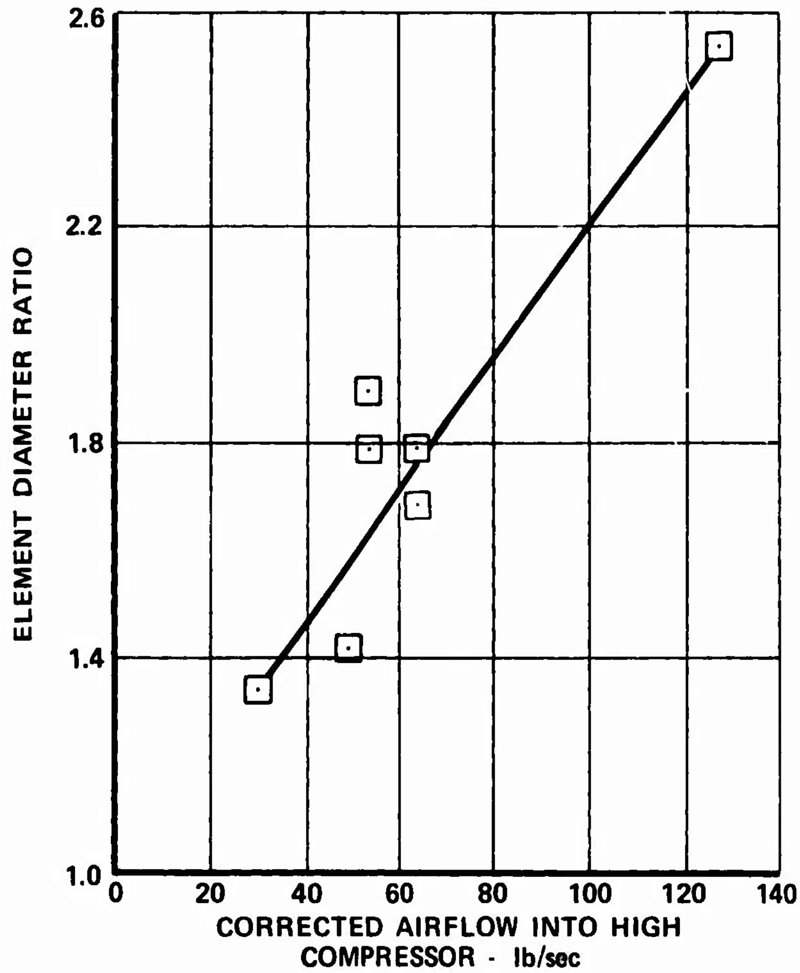

Figure 29. High Rotor Roller Bearings at Sea Level Takeoff; Element Diameter Ratio vs Corrected Airflow Into High Compressor.

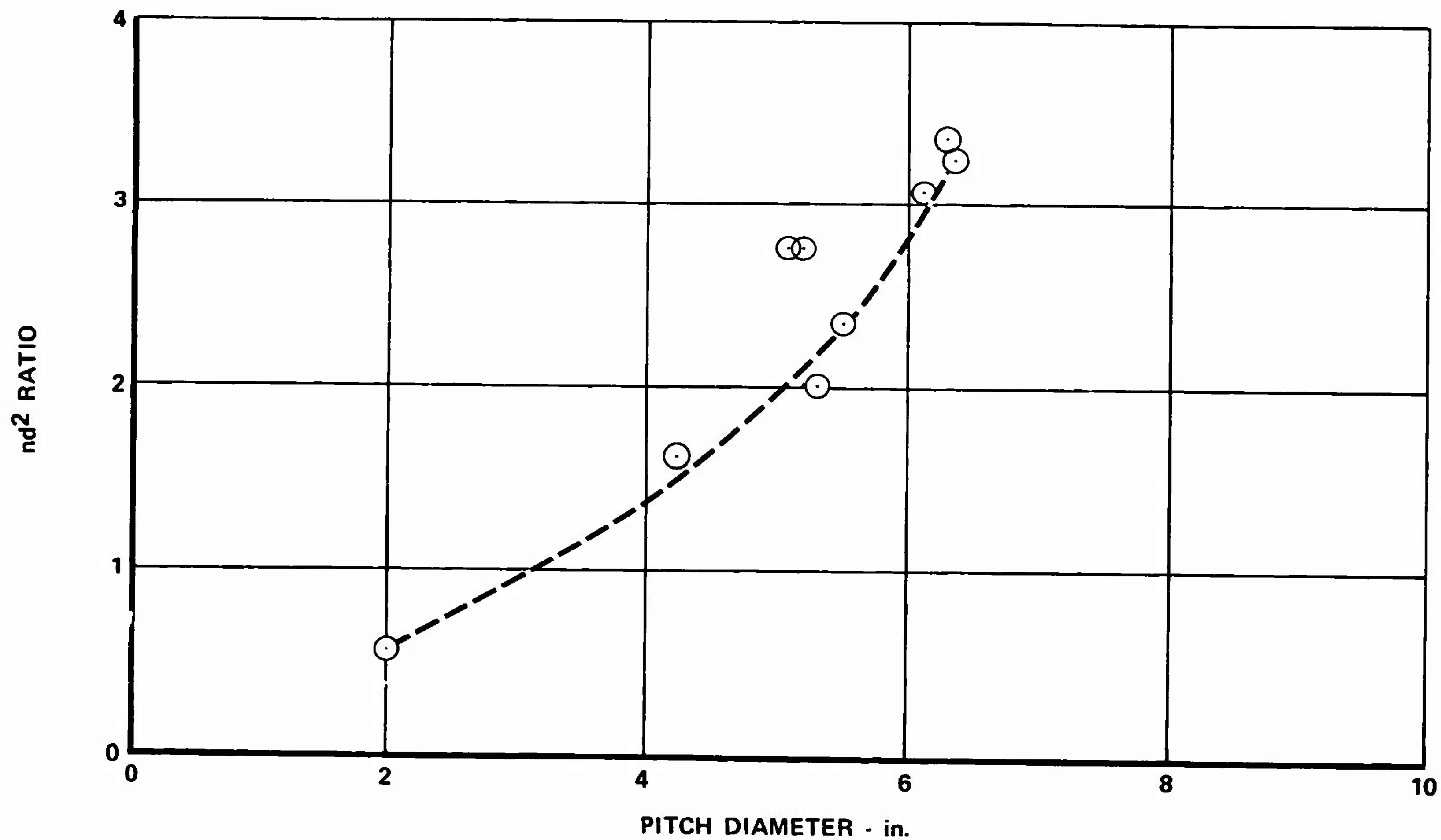

Figure 30. Low Rotor Ball Bearings; nd^2 Ratio vs Pitch Diameter.

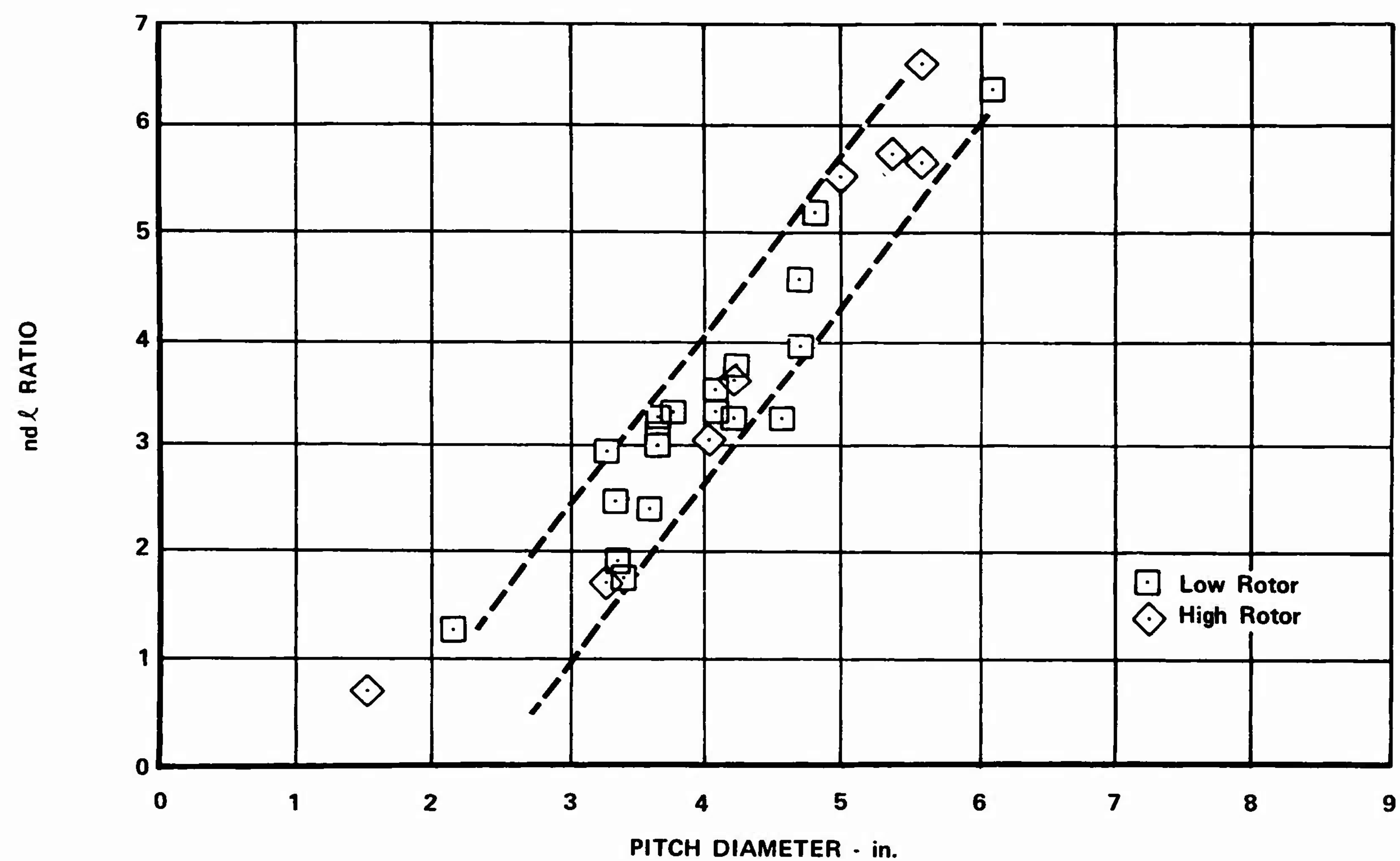

Figure 31. High and Low Rotor Roller Bearings; ndℓ Ratio vs Pitch Diameter.

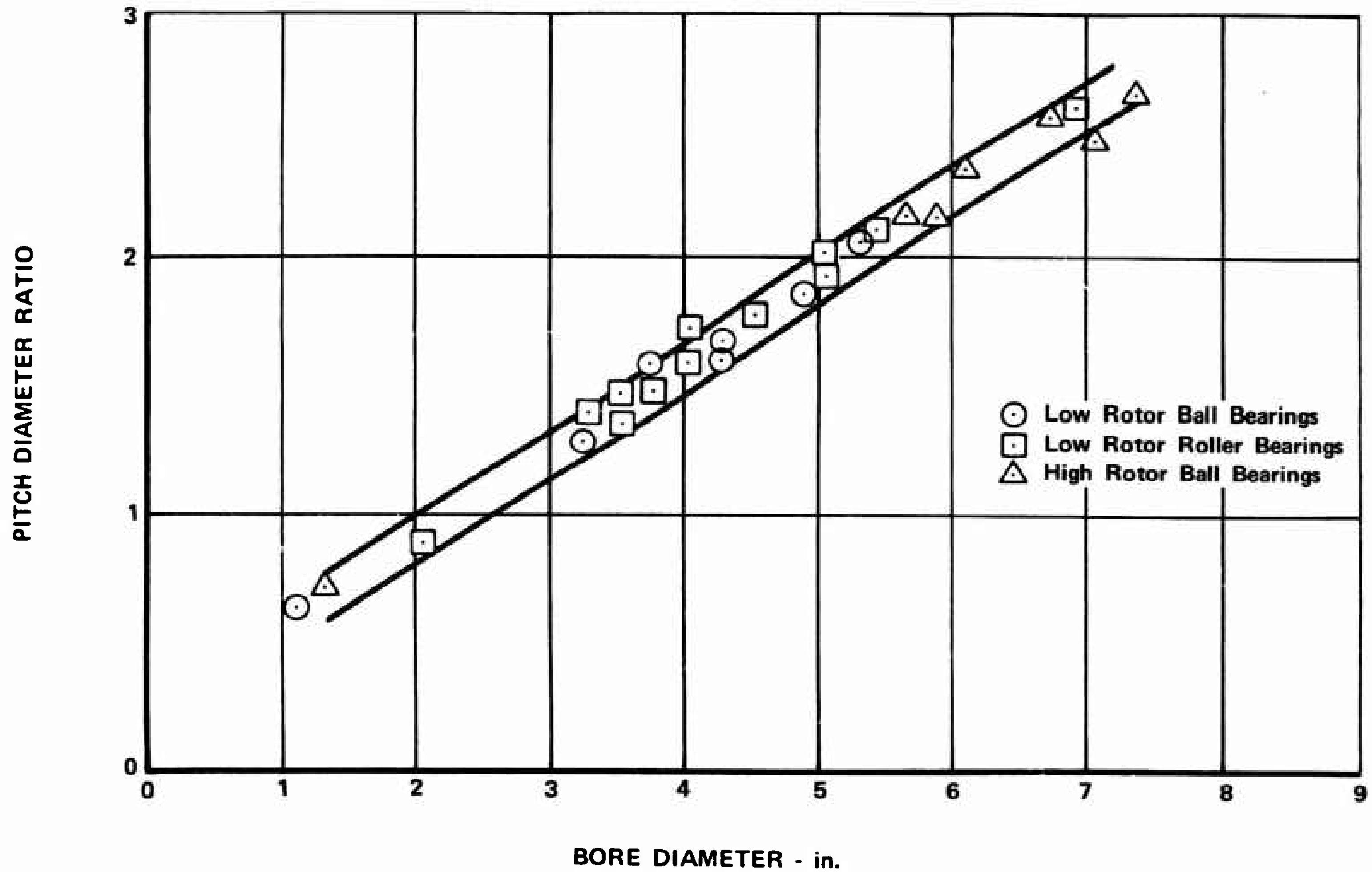

Figure 32. High and Low Rotor Ball Bearings and Low Rotor Roller Bearings; Pitch Diameter Ratio vs Bore Diameter.

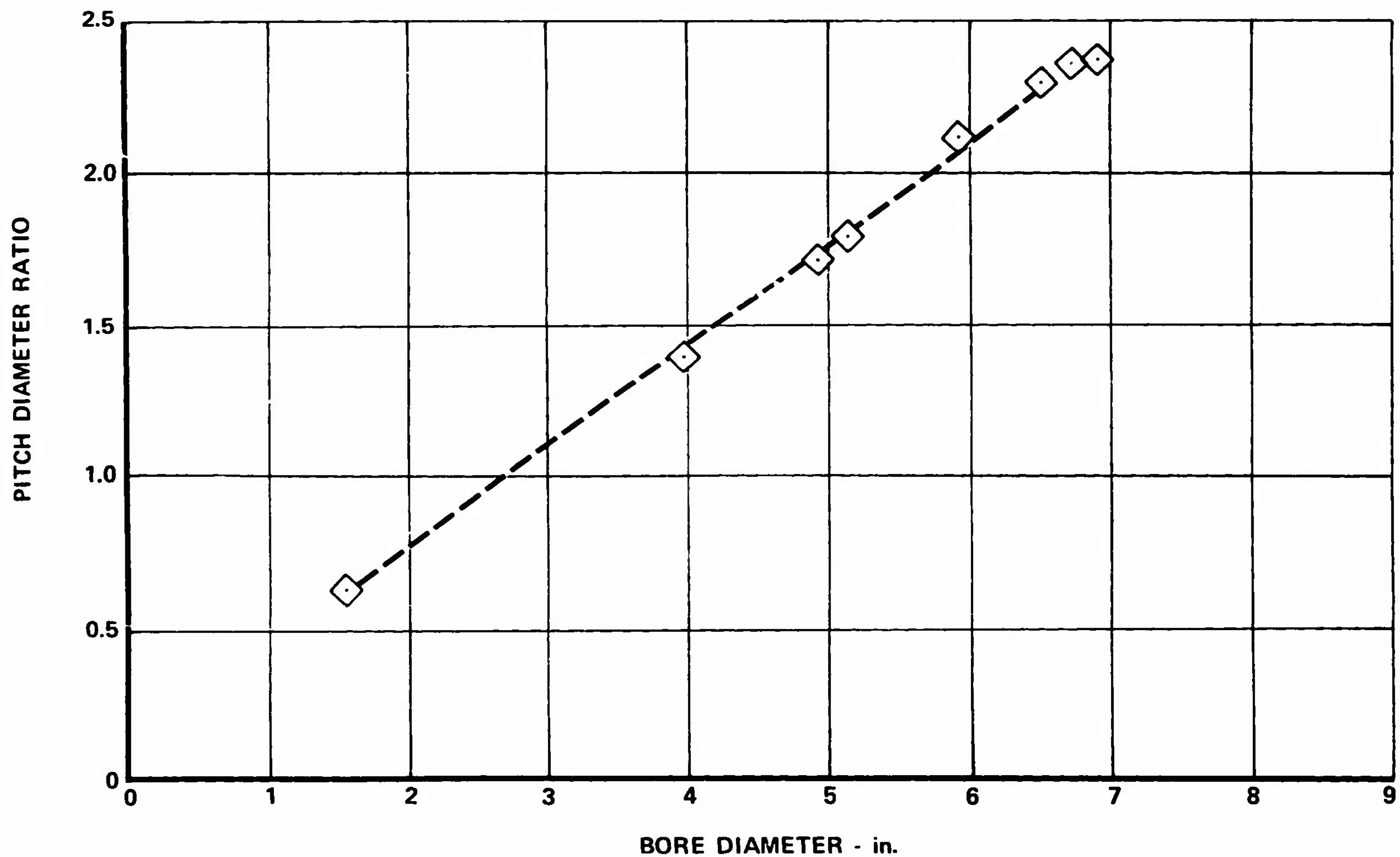

Figure 33. High Rotor Roller Bearings; Pitch Diameter Ratio vs Bore Diameter.

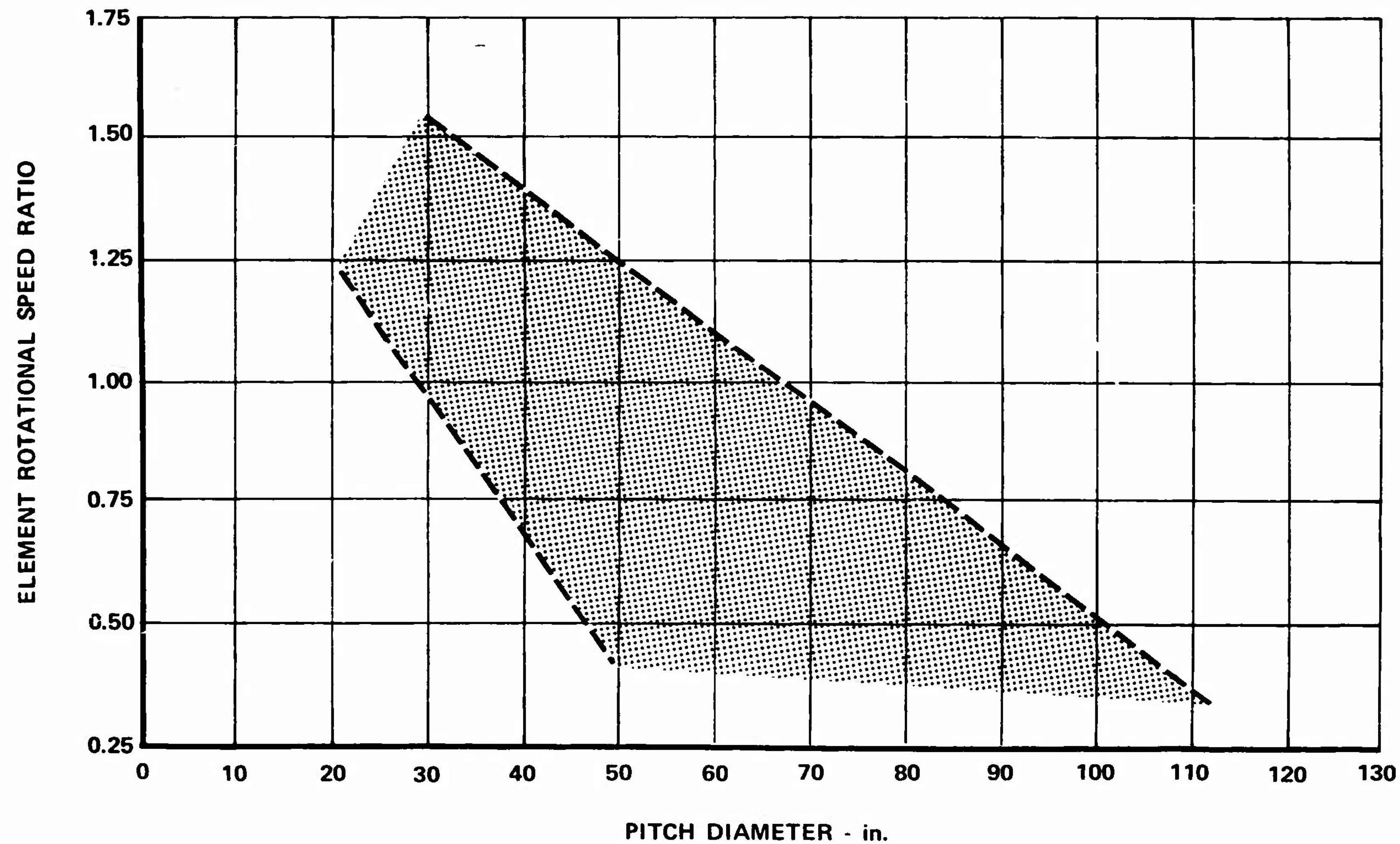

Figure 34. Low Rotor Ball and Roller Bearings at Sea Level Takeoff; Element Rotational Speed Ratio vs Pitch Diameter.

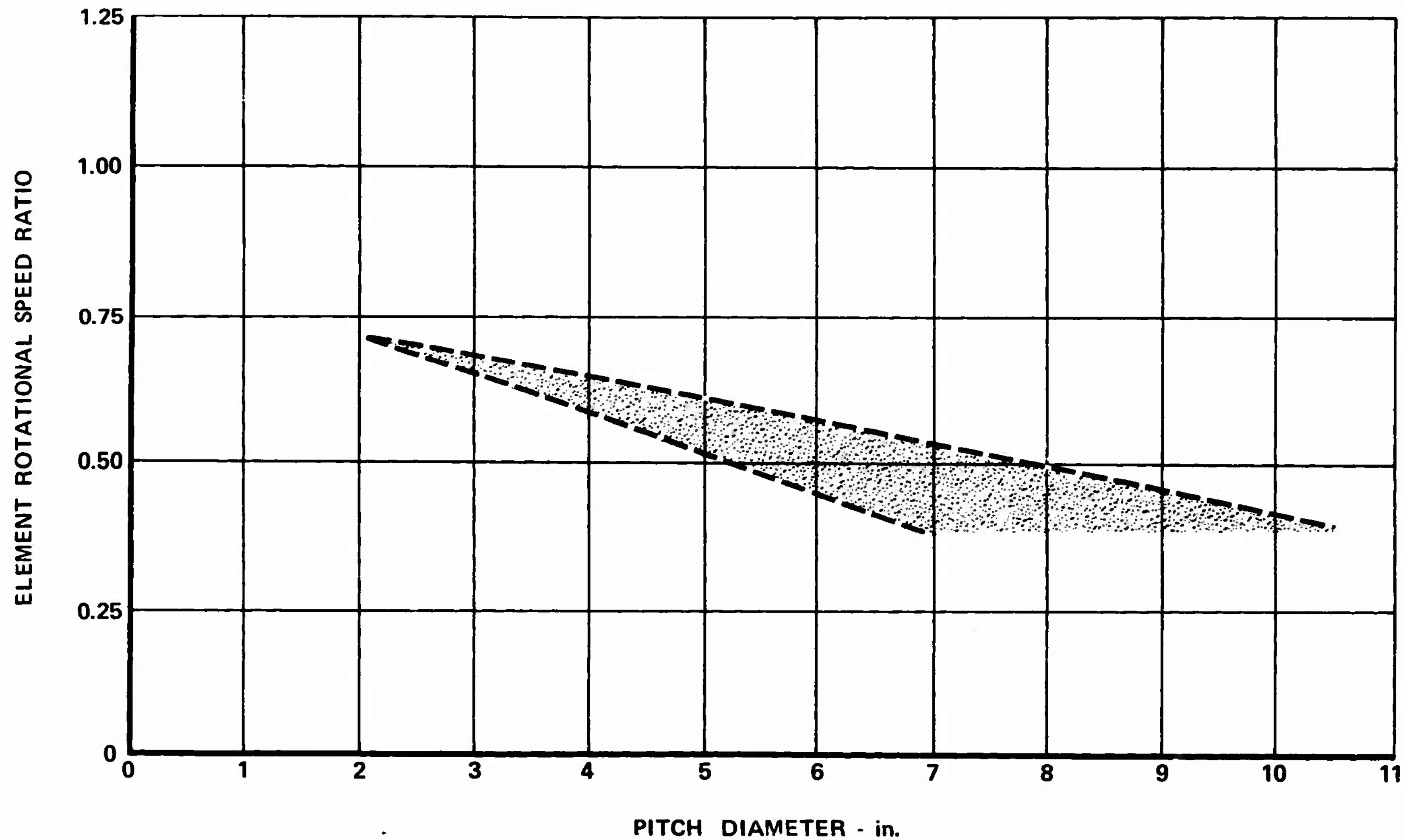

Figure 35. High Rotor Ball Bearings at Sea Level Takeoff; Element Rotational Speed Ratio vs Pitch Diameter.

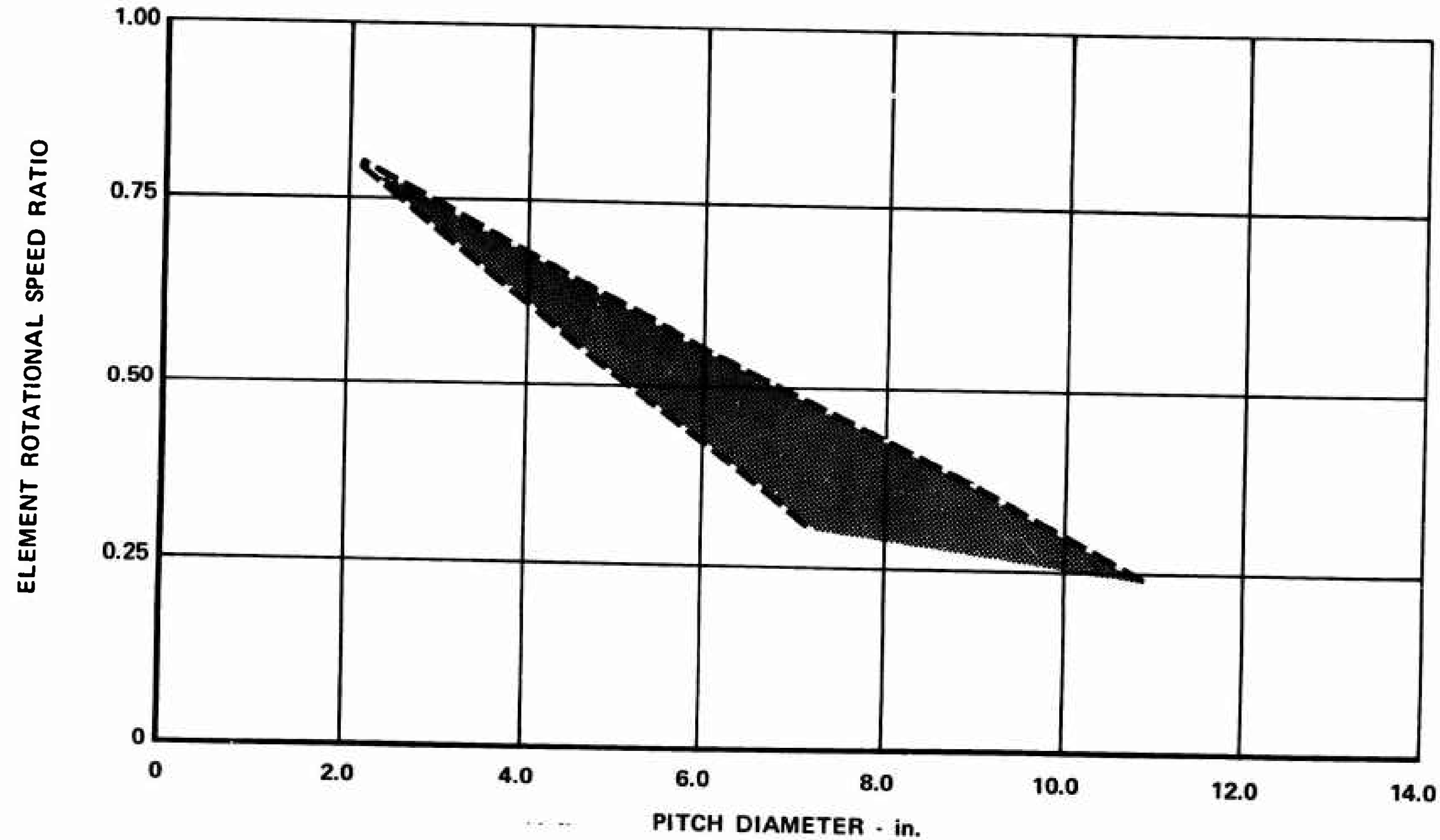

Figure 36. High Rotor Roller Bearings at Sea Level Takeoff; Element Rotational Speed Ratio vs Pitch Diameter.